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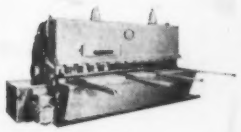

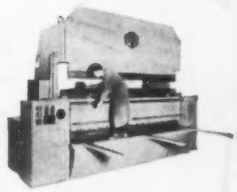

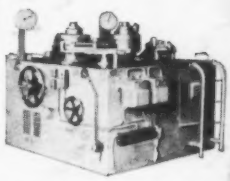

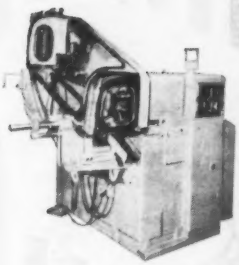

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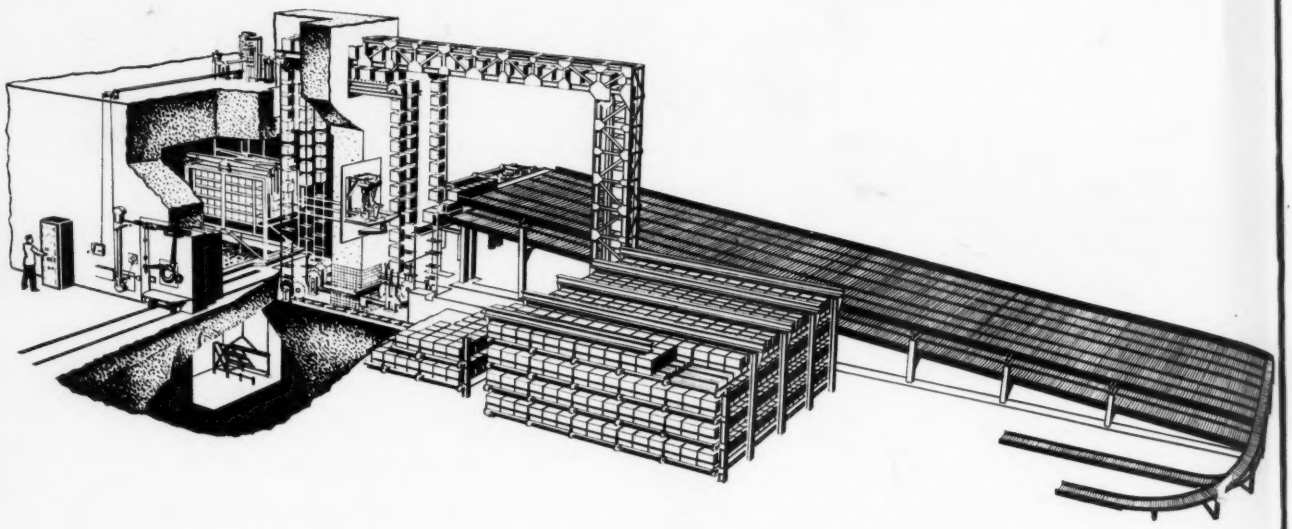

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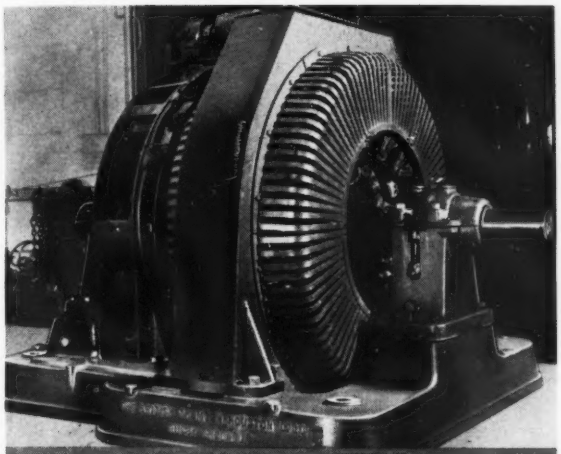

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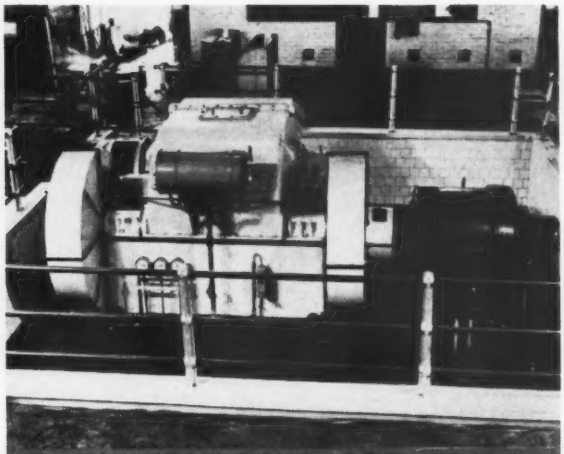

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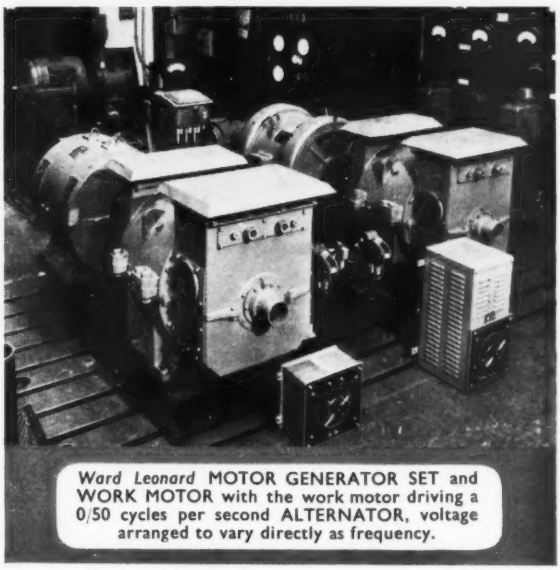

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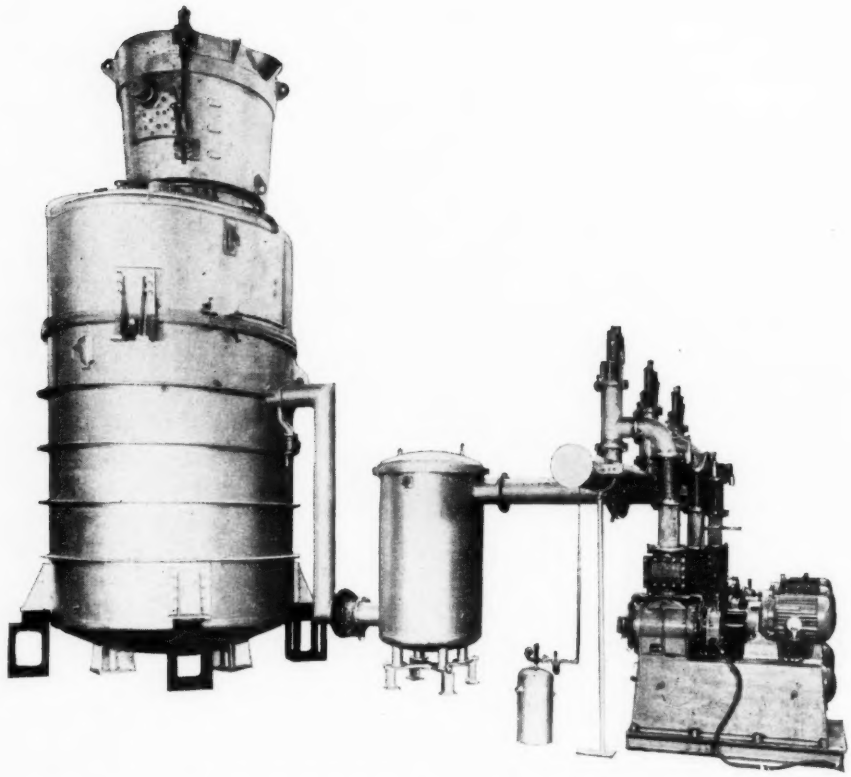

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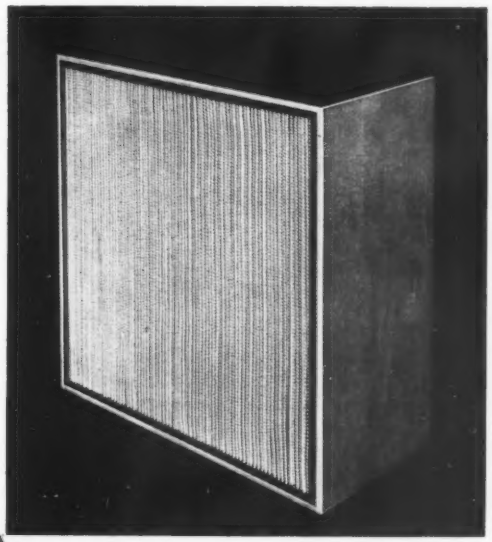

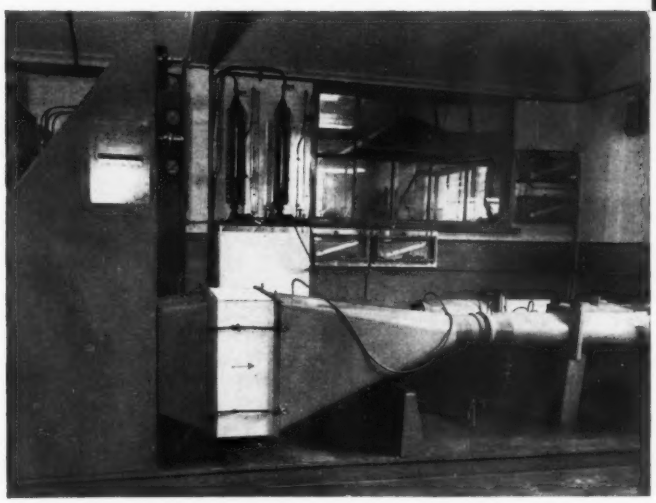

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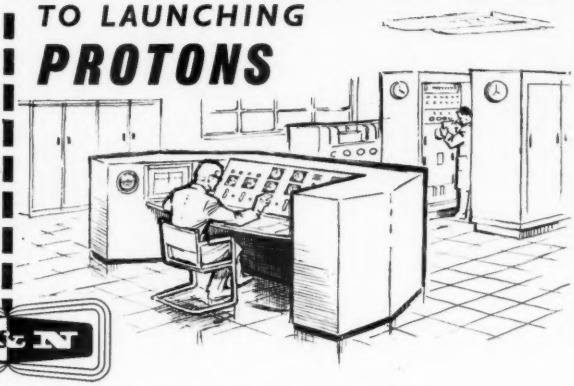

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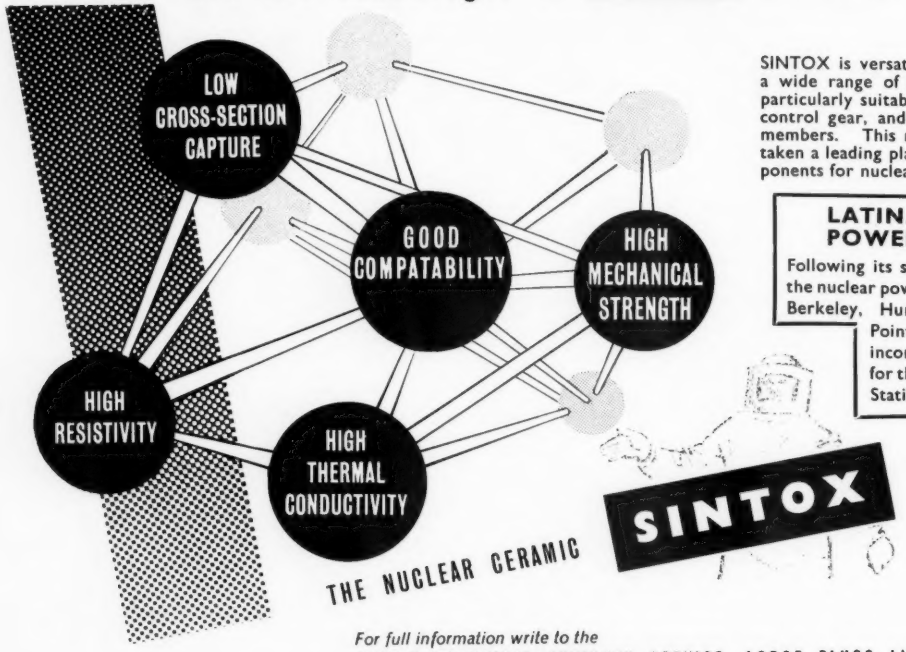


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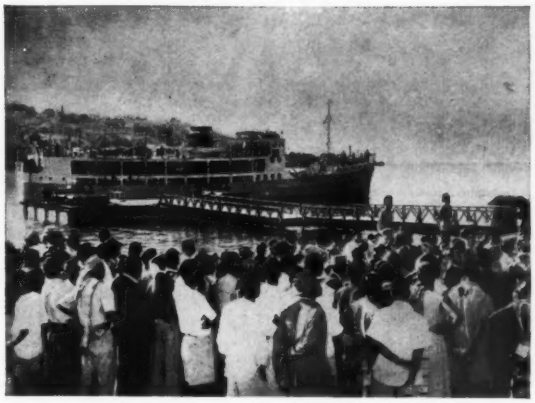

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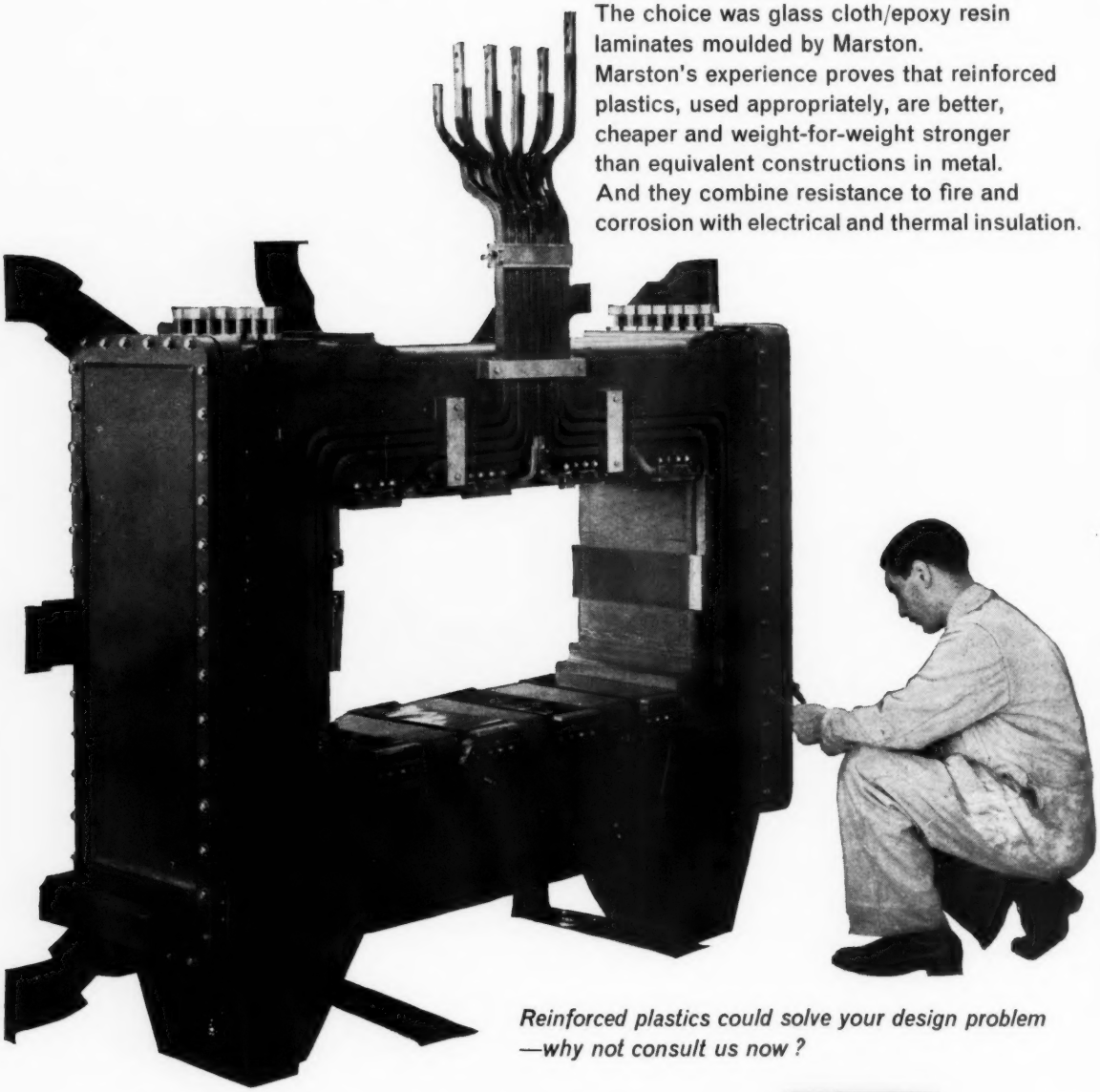

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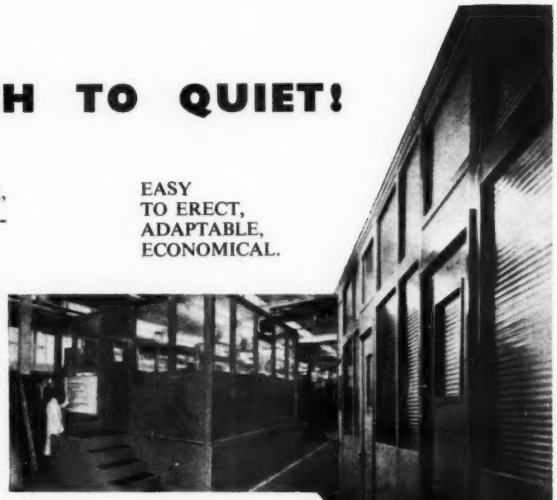

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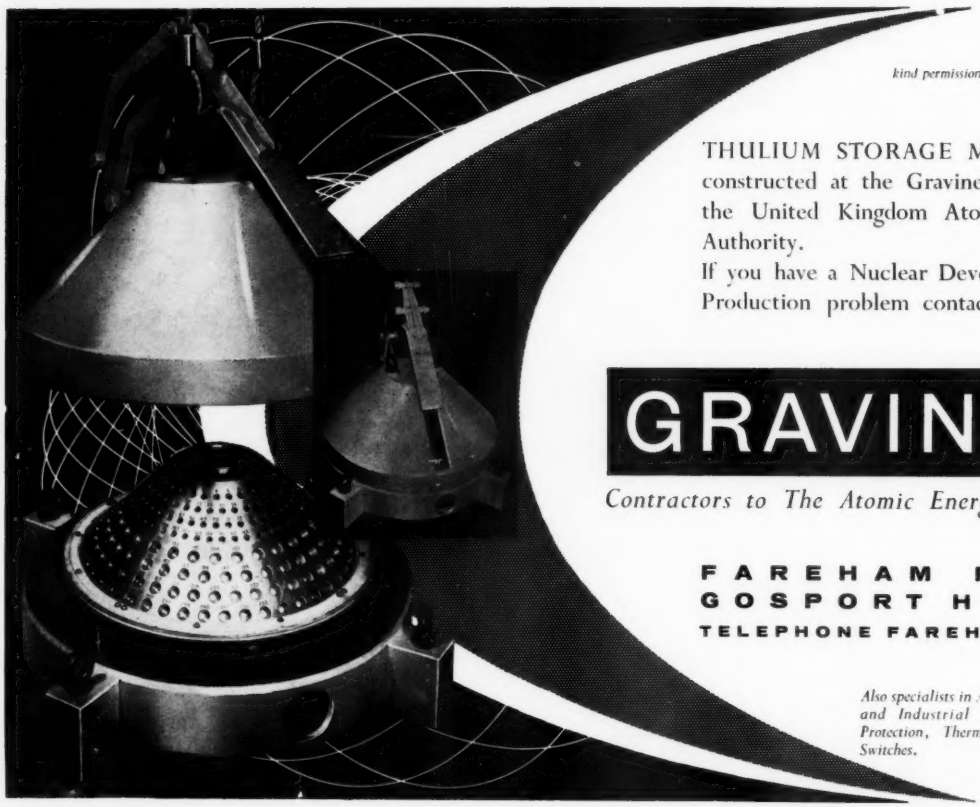

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**United States:** Prof. G. Arfken, *Miami University, Oxford, Ohio;* Prof. J. P. Bradish, *Marquette University, Milwaukee;* Prof. P. R. Camp, *Polytechnic Institute of Brooklyn, New York;* Dr. L. Cochran, *University of Kentucky;* Dr. B. E. Cohn, *University of Denver;* Prof. B. Crasemann, *University of Oregon;* Dr. J. W. Culvahouse, *University of Oklahoma;* Prof. H. J. Ermenc, *Dartmouth College, New Hampshire;* H. J. Gomberg, *University of Michigan;* G. A. Greathouse, *University of Florida, Gainsville;* T. M. Hahn, Jnr., *Virginia Polytechnic Institute, Blacksburg;* Dr. W. W. Havens, Jnr., *Columbia University, New York;* G. A. Hawkins, *Purdue University, Lafayette, Indiana;* Prof. V. P. Henri, *Northeastern University, Boston;* Prof. M. J. Jakobson, *Montana State University, Missoula;* Prof. J. A. Lockwood, *University of New Hampshire, Durham;* Dr. J. K. Major, *Western Reserve University, Cleveland;* Dr. S. F. Malaker, *Newark College of Engineering, New Jersey;* A. C. Menius, Jnr., *University of North Carolina, Raleigh;* Dr. G. Minard, *Bucknell University, Lewisburg, Pennsylvania;* V. E. Parker, *Louisiana State University, Baton Rouge;* Dr. F. B. Porzel, *Illinois Institute of Technology, Chicago;* J. A. Sauer, *Pennsylvania State University;* G. K. Schoepfle, *Kent State University, Ohio;* M. Schwartz, *University of Louisville;* Prof. W. E. Stephens, *University of Pennsylvania, Philadelphia;* Dr. C. D. Thomas, *West Virginia University, Morgantown;* Prof. L. Titone, *Manhattan College, New York;* Prof. B. Tolbert, *University of Colorado, Boulder;* R. E. Turley, *University of Utah, Salt Lake City;* Dr. J. Walton, *Oregon State College, Corvallis;* Prof. J. B. West, *Oklahoma State University, Stillwater.*

**U.S.S.R.:** Prof. Sheglyayev, *Moscow Technical Institute.*

**Yugoslavia:** Dr. M. V. Susic, *Institute of Nuclear Sciences, Belgrade.*



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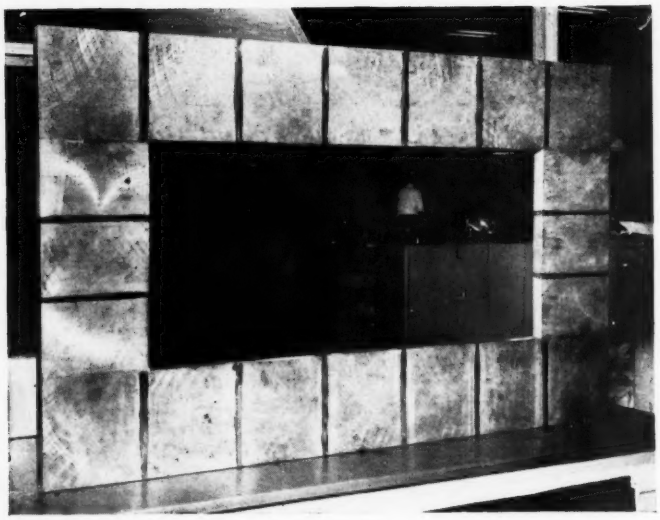
# 7 GeV PROTON SYNCHROTRON

## Mullard and Nimrod



*Photograph showing one of the 5′ 5″ x 3′ 5″ x 1.5″ Ferroxcube frames used in the h.f. accelerator unit of Nimrod.*

Mullard has supplied the cores for the h.f. accelerator unit for Nimrod, the 7 GeV Proton Synchrotron which is a major project at the new Rutherford High Energy Laboratory of the National Institute for Research in Nuclear Science at Harwell.

This accelerator unit consists of twenty-eight frames of a specially developed Ferroxcube material wound as a transformer. The total weight of these frames is almost 6 tons and they are probably the largest sections of ferrite material in existence, each frame measuring 5′ 5″ x 3′ 5″ x 1.5″. Accuracy of the machining and assembly of the complete frames was so critical that each frame had to pass stringent close tolerance tests carried out by specialised optical instruments.

Mullard's accumulated knowledge and wide practical experience have enabled them to make a significant contribution to this important national research project. This knowledge and experience allied to the Company's considerable research and production facilities, forms part of the comprehensive service available to all users of magnet materials in research and industry.

Mullard

MULLARD LTD., COMPONENT DIVISION, MULLARD HOUSE, TORRINGTON PLACE, LONDON, W.C.1

*Interior view of the circular hall in which NIMROD will sit. In the immediate foreground are the plates on which the magnet sectors stand; above is one of the cranes used for handling equipment during assembly of the machine*

# NIMROD

## BRITAIN'S 7 GeV PROTON SYNCHROTRON

*by* J. J. Wilkins and A. J. Egginton

*National Institute for Research in Nuclear Science*

BRITAIN'S latest large-scale venture into the field of high energy nuclear physics is the construction of a high intensity proton accelerator. This machine, given the name NIMROD, is scheduled to provide an output of $10^{12}$ protons/sec (or about one-sixth microampere) at a peak energy of 7,000 MeV. This corresponds to a proton velocity 0.993 of the velocity of light.

The site chosen for NIMROD is the recently created Rutherford High Energy Laboratory of the National Institute for Research in Nuclear Science, immediately adjacent to the Atomic Energy Research Establishment at Harwell. A team of scientists and engineers from the Atomic Energy Authority has been formed to solve the complex problems of design and construction. The extensive building and civil engineering work is nearing completion and the first components for NIMROD are now being installed. Initial tuning-up and operation are expected to begin in 1962.

### *Two Principal Units*

NIMROD consists essentially of two separate accelerators—a low energy linear accelerator, or "injector," followed by a much larger high energy stage, the synchrotron proper. The need for these two parts follows from various factors which make it impossible to accelerate protons from rest by means of a synchrotron alone. The NIMROD injector is designed to produce several milliamperes (peak) of protons with 15 MeV energy. At this energy they can be accepted by the synchrotron for acceleration to the full energy.

The synchrotron itself consists operationally of two main components, a large ring-shaped electromagnet and a radio frequency accelerating system. The low energy particles from the injector enter a vacuum chamber located between the poles of the electromagnet, and then proceed to "orbit" around a more or less circular path 155 ft in diameter, guided and focused (but not accelerated) by the magnet field.

Acceleration of the protons is the function of the radio-frequency accelerating unit, which is built into the

ring system so that the protons pass through once each revolution. The unit comprises a pair of resonant cavities in which radio-frequency electric fields are developed imparting a 5-7 KeV kick to the protons on each transit. After about $1\frac{1}{4}$m. orbits completed in a total time of 0.7 sec, the required 7 GeV is reached.

### Magnetic Field Increases

As the proton energy and velocity increase, the required strength of the magnetic guide field also increases, from an initial low value to a maximum of 14,000 gauss. Thus, the excitation current fed to the magnet windings has to be increased from zero to peak value in 0.7 sec, subsequently falling to zero again ready for another proton pulse to be injected and accelerated. The power supply needed to excite the magnet in this way has to be capable of a peak output of some 115 MW.

The frequency of the radio-frequency accelerating field also has to increase as the proton velocity—and therefore orbital frequency—increases. Fortunately, an automatic "phase lock" exists between the r.f. field and the protons; if this was not so it would be practically impossible to keep the r.f. in synchronism with the protons throughout the $1\frac{1}{2}$m. revolutions. Even so, the frequency of the accelerating field must be made to follow the magnetic guide field to a precision of about one part in 1,000.

**PRINCIPAL PARAMETERS OF NIMROD**

| | |
|---|---|
| Maximum proton energy | 7 GeV |
| Maximum magnetic field | 14,000 gauss |
| Mean orbit radius | 77 ft 6.38 in. |
| Number of magnet sectors | 336 |
| Energy at injection | 14.9 MeV |
| Magnetic field at injection | 295-298 gauss |
| Magnetic steel weight | approx. 7,000 tons |
| Magnetic copper weight | approx 250 tons. |
| Magnet aperture, width | 36 in. |
| Magnet aperture, height | $9\frac{1}{2}$ in. |
| Pulse repetition rate at peak energy | approx. 30 |
| Expected output | $10^{12}$ protons/pulse |
| Accelerator system frequency range | 1.4-8.0 mc/s |
| Number of orbits during acceleration | $1.2 \times 10^6$ |
| Acceleration time | 0.7 sec |
| Total peak rating of motor-alternators (2) in magnet power supply | 115 MVA |

It can thus be seen that particles are produced by the synchrotron in pulses. These are of variable duration and may be emitted at rates up to 30 per minute at peak energy.

In plan view the ring magnet is in eight identical units, or octants, each on a 45° arc. Spaces alternately 11 ft and 14 ft between one octant and the next accommodate various machine components such as the r.f. accelerator unit.

### Design of Magnet

The whole magnet is of laminated construction to avoid excessive eddy current effects. Furthermore, great care in design, manufacture and assembly is needed since the particular spatial distribution of magnetic field required must be produced very precisely at all levels of exciting current.

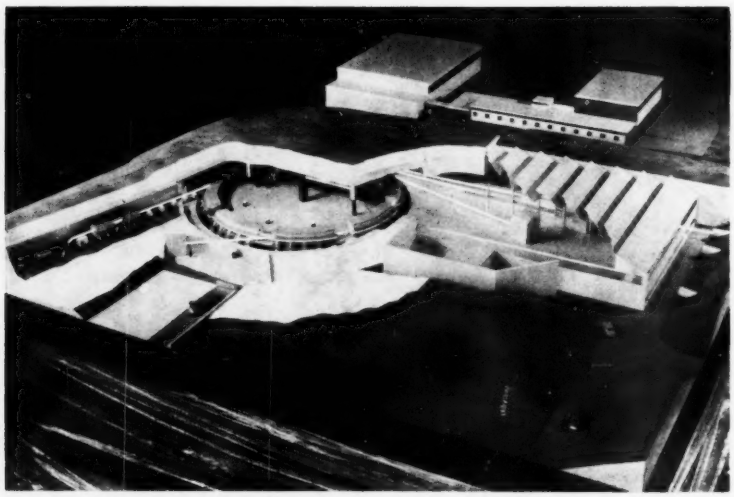
The yoke of an octant consists of 42 C-shaped slices, or sectors, each 10 ft 5 in. high × 9 ft 3 in. wide and $12\frac{1}{2}$ in. thick. The sectors weigh $19\frac{1}{2}$ tons each and are placed in position with the C-gaps facing radially outwards to give maximum accessibility. Polepieces of somewhat complex design are fitted to the upper and lower surfaces of the gaps.

The $12\frac{1}{2}$ in. thickness of a yoke sector is made up from about 46 plates of 1 per cent. silicon steel. The plates are fully annealed and flattened, cleaned and then coated with insulation. The sector is held together by bolts and by some edge welding; the latter adds to the rigidity of the structure without increasing the eddy currents significantly. Finally, the C-gap is machined to a few thousandths of an inch tolerance. Subsequent transport and handling of these heavy laminated structures requires careful control to avoid any distortion of the gap dimensions.

### Polepiece Construction

Each polepiece weighs 800 lb and consists of a stack of about 450 steel laminations 0.020-0.030 in. thick. These very accurately formed laminations are glued together with an epoxy resin—glass cloth adhesive to accurate finished dimensions. The total surface area of steel to be glued exceeds 1m. sq.ft.

Each magnet octant has its own 42-turn winding fabricated from copper bars of $2\frac{5}{8}$ in. × $1\frac{3}{8}$ in. section. The bars are extruded in single lengths of up to 55 ft and have a



**Sectioned view of model of NIMROD buildings with machine inside. The injector can be seen to the left in its own section of the building while the synchrotron itself is visible in the central hall. Particle beams can be seen issuing from the machine into the experimental area on the right of the picture**

central hole to permit water cooling. The insulation used between turns is essentially the same as that used in modern turbo-alternators.

### 250 tons of Copper

The windings of the octants are all connected in series and carry a peak current of 9,150 amps. The total power dissipation is 3 MW (mean) at the normal repetition rate of the machine. The total weight of copper in the winding is about 250 tons. Adequate clamping of the windings to the main magnet structure poses a difficult problem especially at the ends of the octants. Space and hence access are limited and the severe pulsed duty implies considerable risk of fatigue fractures. A system of pneumatic pressure pads has been adopted so that full clamping is maintained in spite of varying degrees of compaction.

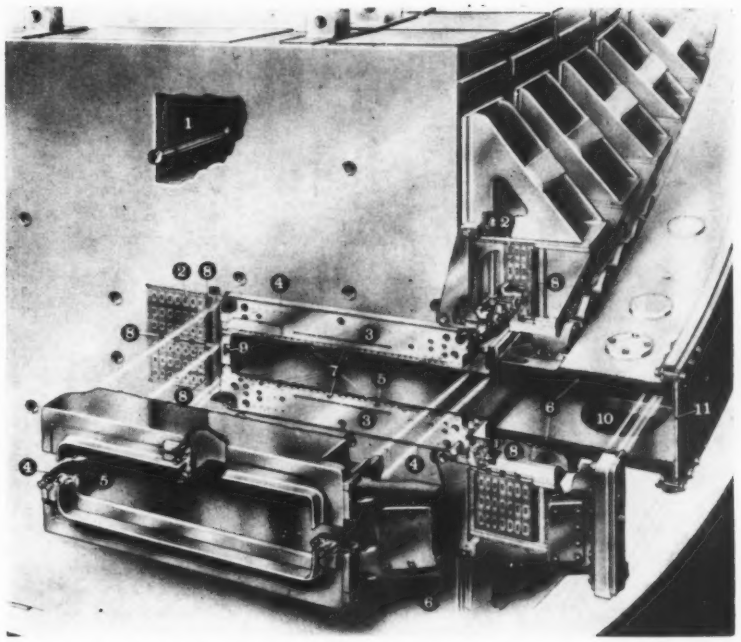
The magnet and its windings form a highly inductive circuit which stores 40 megajoules of energy at the peak current of 9,150 amps. Ideally the power supply would feed the energy into the circuit and then (by reversal of voltage) remove it again, the whole process being repeated every 2 sec. However, the copper and iron losses require an extra 6 megajoules, so that in practice 43 megajoules are fed into the magnet and 37 megajoules recovered each pulse.

The basis of a power supply to perform this duty is provided by a rotating set, on a single shaft, comprising two 60 MVA, 1,000 rev/min alternators and two 24 ton flywheels driven by two 5,000 h.p. induction motors. The 50 c/s alternator output is converted to the required form by eight 12 MVA phase—splitting transformers, followed by 96 single—anode rectifier—inverter valves.

### Stress Analysis Needed

When energy is being fed into the magnet the valves work in their rectifying condition and the flywheels (assisted by the motors) drive the alternators. When energy is being extracted from the magnet the valves invert causing the alternators to act as synchronous motors driving the flywheels. Thus there are severe torque reversals every 2 sec. and much detailed stress analysis has been needed for the design of the rotating set and its foundations.

The presence of the flywheels reduces the speed variations of the rotating machinery to about 4 per cent. In particular, the variations in power input to the induction motors (taken from the National Grid) are reduced to acceptable levels.




**View of cross section through 7 GeV Magnet Octant.** Key to numbers:—1 Magnet sector; 2 Magnet coils; 3 Pole tips; 4 Outer vacuum chamber (low vacuum); 5 Inner vacuum chamber (high vacuum); 6 Header chamber (high vacuum); 7 Pole face windings; 8 Pressure pads; 9 Pole tip jack; 10 Main pumping port; 11 Beam exit window.

### Most Difficult

The toroidal vacuum chamber incorporated between the ring-magnet poles has presented perhaps the most difficult design and manufacturing problems of any encountered on NIMROD. Most of these stem from the need, for eddy current reasons, to use a largely non-metallic construction.

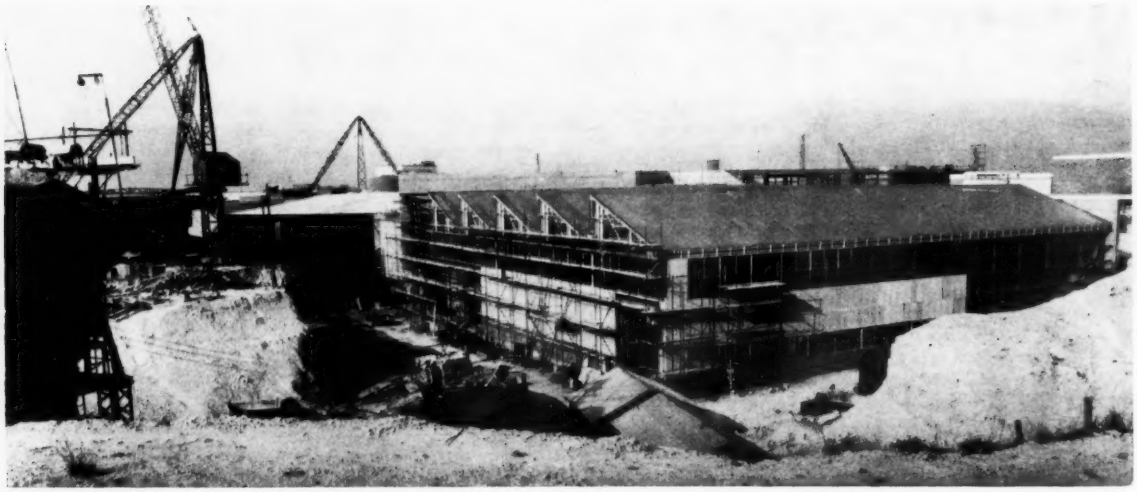
The design adopted is based on eight double-walled vessels of glass reinforced epoxy resin each the whole length of an octant (55 ft). An outer vessel with $\frac{1}{8}$ in. walls is sandwiched between the poles and yoke of each magnet octant. An inner vessel of similar length and thickness is placed within the octant gap and evacuated to $10^{-6}$ mm of mercury while the space between the two vessels is evacuated to about $10^{-2}$ mm of mercury. Thus the magnet structure supports practically all the atmospheric pressure load and the inner high vacuum vessel has only a small differential pressure to withstand. This arrangement minimizes not only the wall thickness of the vessels but also the significance of structural weakening due to radiation damage.

Much research has gone into the choice of the best available formulation of resin and hardener and production of the long curved vessels involves many novel techniques and problems.

### Forty Diffusion Pumps

The inner vessels are evacuated by a total of 40 24 in. oil diffusion pumps which exhaust the vessel via a substantial header chamber of similar construction to the main vessels.

The gaps between octants are bridged by single walled vessels, incorporating expansion bellows and shut-off valves, allowing a clear high vacuum path measuring at least $9\frac{1}{2}$ in. vertically and 36 in. radially, round the ring in which the protons can travel.



**An exterior shot of the recent state of construction work. It shows the magnet building (the domed structure in the left background) with the main experimental area in the foreground. At present the magnet room has no earth on its roof or sides**

The complete r.f. accelerator system comprises the accelerator unit already referred to and the electronic equipment required to drive it. The detailed design is complex and only a few points can be mentioned here.

The accelerator unit itself, through which the protons pass, operates over a frequency range of 1.4 mc/s to 8.0 mc/s. The two identical resonant cavities in the unit have to be tuned over this frequency range and for this purpose they are partially filled with 5½ tons of ferrite. Bias windings polarize the ferrite magnetically to any required degree, thereby tuning the cavities. In practice the system operates automatically, *i.e.*, the resonant frequency of the cavity always matches the frequency of the power fed in.

Control of the power fed to the cavity starts from the measurements of the magnetic guide field in the ring magnet. This signal is used to compute the appropriate frequency programme for the r.f. unit. A chain of amplifiers boosts the signal to the 40 kW power level necessary for operation of the unit as a whole.

## The Injector

As indicated above, the injector is a complete accelerator by itself. Rather like NIMROD, it comprises more than one stage of acceleration.

The protons are first produced in an ion source (an electric discharge in hydrogen) and accelerated between high voltage electrodes to an energy of 600 KeV. A revolving drum electrostatic generator of compact design supplies the 600 kV potential.

At this energy the protons can be accepted into the linac for acceleration to 15 MeV. The principal component of the linac is a copper tube 67 in. in diameter and 44 ft long. This is designed to act as a resonant cavity at a frequency of 115 mc/s and strong electric fields are produced along the axis of the tube. A series of 48 tubular copper electrodes, or " drift tubes " placed along the axis modify the electric fields so that the protons passing through are strongly accelerated. Magnetic quadrupole lenses are built into the electrodes to maintain the protons in a narrow pencil beam. To perform this task properly the magnetic axes of all the lenses must be within one-thousandth of an inch of each other down the whole length of the tank.

The tuning of the cavity is very critical and temperature control to $\pm 3°C$. is necessary. Water cooling is used to remove the 800 kW (peak) of r.f. power that is dissipated in the cavity as a whole.

The whole assembly is enclosed in a 32-ton vacuum vessel 8 ft in diameter and 46 ft long which is evacuated to $10^{-6}$ mm of mercury by four 24 in. mercury diffusion pumps.

## Radiation Hazards

When NIMROD is operating, the radiation round the synchrotron will be lethal and large quantities of shielding are necessary to reduce it to acceptable levels in surrounding areas. The maximum use has been made of the terrain (consistent with economics). The machine itself sits below outside ground level in a large circular hall some 200 ft in diameter.

## Roofing a Problem

The principal problem in the design of this building has been to provide a roof of sufficient thickness for radiation purposes (15 ft of concrete or equivalent) which is not too severe a load on the ring-magnet foundation. An additional complication to the building design is the need for access to the machine in experiments. For this purpose one side of the magnet building (about 120° in arc) has been left open at beam level and the resulting gap stemmed by a mobile " concrete wall " consisting of some 150 25-ton concrete blocks each 15 ft long × 10 ft wide and 2½ ft deep assembled in stacks of five. These are arranged so that their effective shielding thickness is some 30 ft of concrete at beam level.

The ring-magnet must sit on a foundation which is capable of withstanding both the load of the magnet (some 7,000 tons) and the load of the roof above. It must perform this task without distorting from a true plane by more than 0.04 in. during the life of the machine. This requirement has led to the adoption of a massive disc foundation some 20 ft thick.

In order to avoid disturbance of the magnet position due to movement of heavy loads adjacent to the machine the foundations have been split into sections. In particular the magnet foundations and that of the mobile shielding wall are completely separate.

### Use of NIMROD

NIMROD is intended entirely for basic nuclear research. Scientists from universities, the Atomic Energy Authority and elsewhere will study the interactions between the protons from the machine and target nuclei. It is already known that a whole new class of sub-nuclear particles—the so-called "strange" particles—are created in energetic collisions of this kind. Close study of these and other fundamental particles seems essential for a deeper understanding of the nucleus and the way it is held together. A primary aim in the design of NIMROD has been to produce such particles in significantly greater intensities than are at present available from other accelerators.

#### Contractors and Suppliers

Among contractors and suppliers of equipment for the construction of the synchrotron are:—British Brown Boveri, Ltd. (converter equipment); English Electric Co., Ltd. (rotating machinery for power supply rectifiers for test rigs); Marston Excelsior, Ltd. (development and manufacture of main vacuum vessels); Metropolitan-Vickers Electrical Co., Ltd. (manufacture of magnet coils); J. Sankeys, Ltd. (magnet sectors); British Copper Refiners, Ltd. (blister copper for magnet coil); J. Booth & Son (Bolton), Ltd. (extrusion of copper for magnet coils); Edwards High Vacuum, Ltd. (high vacuum equipment for injector, main vacuum pumping equipment); London Aluminium (Containers), Ltd. (R.F. liner for injector); Matthew Hall & Co., Ltd. (supply of daywork mechanical labour); H. & E. Lintott (sector test rigs, etc.); Mullard, Ltd. (ferrite matrices for storage units); Vickers-Armstrongs (Aircraft), Ltd. (design of plant); Anderson Clyde Engineers (25-ton mobile gantry); Babcock & Wilcox, Ltd. (vacuum vessel for linear accelerator); British Thomson-Houston Co., Ltd. (modulator for R.F. supply to injector); David Brown Construction Equipment, Ltd. (towing tractor); Carrimores Six-Wheelers, Ltd. (transporter for sectors); C. & N. Electrical, Ltd. (supply of electrical and electronic control equipment); Electrodynamic Construction Co. (H.F. alternator for injector); Firth-Vickers, Ltd. (s.s. frames for linear accelerator); General Engineering (Radcliffe) Co. (vacuum roughing pumps); C. W. Glover and Partners Consulting Engineers (loan of staff); Hackbridge & Hewittic Electric Co., Ltd. (R.F. bias supply); J. & E. Hall (R.F. cavity cooling equipment); Hilger & Watts (survey consultancy); A. Imhof, Ltd. (control racks); H. & E. Lintott (miscellaneous components for main machine); Livingston Laboratories (oscilloscopes); Moores (Bournemouth), Ltd. (miscellaneous components for main machine); National Physical Laboratory (survey consultancy); Portsmouth Aviation (E.H.T. mechanical equipment, miscellaneous components for main machine, design contract, E.H.T. platform for injector); Talbot-Ponsonby, Ltd. (support stand and rails for injector D.C. gun); John A. Smith (design contract (plant)); Speedy & Eynon (1951), Ltd. (miscellaneous components for main machine); S.A.M.E.S. France (650 kV H.V. equipment for injector, H.V. supply for proton gun); Technical Design and Tool Co. (design contract (plant)); Coventry Gauge & Tool Co. (metrology jigs); General Electric Co., Ltd. (D.C. generators).

Among contractors, etc., for building and general services are Faulkner and Partners (quantity surveying); Merz and McLellan (Consulting Engineers); W. E. Chivers & Sons (main civil engineering contractors); N. G. Bailey & Co. (lighting and small power installation); Z. D. Berry & Sons, Ltd. (heating and hot water services); Matthew Hall & Co., Ltd. (air-conditioning equipment); Film Cooling Towers (1925), Ltd. (evaporative cooling units); Rubery Owen & Co., Ltd. (structural steel); Taylor Woodrow Construction, Ltd. (arcon buildings); Wharton Crane & Hoist Co. (25-ton crane assembly and test building, 3 E.O.T. cranes, magnet buildings and 5 E.O.T. cranes); and Whitehead Iron & Steel Co. (reinforcing rods).

## About the Authors . . .

*J. J. WILKINS graduated in 1944 with honours in electrical engineering from Queen Mary College, London. In the years following 1946, when he went to Harwell, he was concerned with the design of some early synchrotrons, including the one at Glasgow University. After a period of research in nuclear physics he joined the team designing the 50 MeV proton linear accelerator at Harwell, now taken over by the National Institute for Research in Nuclear Science. From 1956, he has been a member of the NIMROD team under Dr. T. G. Pickavance and Mr. L. B. Mullett with responsibility for design of the magnet.*

*A. J. EGGINTON was educated at University College, London, where he took an honours degree in physics in 1951. In 1953 he joined the 50 MeV linear accelerator team at Harwell and three years later moved, with Mr. Wilkins, on to the magnet design of NIMROD. He has also taken a keen interest in the radiation shielding problems of the machine and is now engaged on the design of equipment for dealing with the beams which emerge from it.*

**Another view of the magnet hall showing magnet sectors assembled on their foundation and, in the background, some of the concrete blocks for the mobile shielding wall. In the foreground stands a single sector without polepieces or coils**

# ADVANCED WATER REACTOR SYSTEMS—Part II.

## DESIGN STUDIES OF PLANTS FOR ECONOMIC POWER

**Westinghouse Electric Corporation, of America, have recently completed design studies of three new advanced water reactor systems for power production. All three make use of superheating. The first system—the Combination Plant—which uses both nuclear and fossil fuel was described and discussed last month. The second system—the Integral Boiling Superheating Reactor—in which water is boiled and superheated within the reactor, was also described last month. Here some of the problems associated with the development of this particular system are discussed, together with details of the third, Closed Cycle System**

(*Continued from page 13*)

WITHIN the carbon-steel containment vessel of the Integral Boiling and Superheating Reactor, and completely blanketing the graphite moderator in all its vital areas, is helium under pressure of 100 lb/sq.in. The helium will control heat transfer from the graphite moderator to the pressure tubes, at the same time maintaining the graphite temperature within safe operational limits. The helium control is necessary since the graphite is hot—in fact, about 10 per cent. of the reactor's heat generation is performed by the graphite itself.

The integral boiling and superheating reactor, although a long step into the future, is ultimately a very economical, very efficient 200 MW reactor. A thorough research and development programme coupled with construction of a prototype plant would have to precede a full-scale 200 MW plant.

### Problems to be Solved

Some of the problems that must be solved about this highly advanced reactor concept are as follows:

Control will be a major problem, since within a few inches inside the reactor, it will be necessary to handle temperature differences of nearly 400°F. The answer to this heat control lies in detailed studies that will show how to programme the control rods. The reactor is already designed with a large number of control rods to make this problem easier to solve.

Another aspect of the control problem concerns the flow of the water and steam through the reactor's two sections. The two must be balanced, and adjusted to meet the surge demands of the turbine. Fortunately, the pressure-tube design offers a built-in solution. In the superheat section, a throttle could be installed at the inlet of each tube, and a thermocouple at the outlet. By coupling these into an information feedback system, precision control of the reactor would be possible.

### Need for Economy

Although not an insurmountable problem, several questions about fuel performance in the higher temperatures of the superheat section need to be answered.

A final research and development problem is not really a problem at all, but an effort to make this research as economical as possible by improving its pressure tubes. Perfectly satisfactory pressure tubes for this reactor could be made, but if they could be made from a stronger metal which does not absorb neutrons excessively, the tube walls could be made thinner. This means more efficiency and lower capital investment. For the superheating region tubes, two alloys, Discalloy and Inconel-X are being examined; for the central boiling region, there are Zircalloy, and AM-350. If one of these alloys proves suitable, substantial reductions in power cost would result.

To solve these problems and to ensure the success of the plant, Westinghouse suggest a prototype plant one-tenth the size of the final plant should be built. In this plant, the graphite block would be 11 ft in diameter and 14 ft high. Fifty-six pressure tubes would be located in the centre boiling area, and 24 tubes in the superheat area. Each tube would be 2.7 in. in diameter. Within each pressure tube would be 19 fuel rods, each $\frac{1}{2}$ in. in diameter, and 10 ft in length.

The containment vessel would be 23 ft high, and 12$\frac{1}{2}$ ft in diameter, made of carbon steel $\frac{1}{2}$ in. thick. There would be just two steam drums in this prototype system, each 11 ft long and 4 ft in diameter. The turbine would operate at a steam pressure of 850 lb/sq.in. and temperature of 900°F.

### No Major Difficulties

Westinghouse's third design relates to an all-nuclear power plant which could be built and put into operation without any major research and development problems having to be solved. It is for a 330 MW closed cycle, water moderated plant.

The design for this is the result of a detailed study to establish feasibility and economies of closed cycle plants of up to 400 MW output, with plant start-up to be early 1965. All these plants were established as being feasible within this time scale and the economics of the larger ratings looked particularly promising.

The closed cycle system discussed earlier uses both a primary and a secondary loop as shown in Fig. 3. The primary loop circulates pressurized water through the reactor and a

heat exchanger. Here the heat is transferred to a secondary loop, producing steam which is piped to the turbine. The condenser and other secondary equipment are all conventional designs.

To get a clear impression of the size of this 330 MW reactor, here are a few details about it. The reactor vessel itself weighs 300 tons, stands 41 ft high, and is a little less than 12 ft in inside diameter. Its walls are carbon steel about 10 in. thick, with an inner cladding of 1¼ in. of stainless steel.

## Novel Fuel Loading

The fuel is in the form of uranium oxide pellets clad in either stainless steel or Zircalloy-2. For more uniform heating and better fuel economy, Westinghouse engineers have developed a novel method of loading the core in three levels of enrichment. Looking down on the top of the reactor, visualize three concentric circles into which the fuel elements are loaded. In the inner circle, the fuel enrichment will be about 2.1 per cent.; in the intermediate, 2.6 per cent.; and in the outer circle, 2.9 per cent.

Fuel life for this reactor is three full-power cycles. After each cycle the centre circle of fuel is removed. The second and third layers of fuel are moved toward the centre, and a new outer layer added of 2.9 per cent. enrichment.

The uniform heat rate that will result this way will allow the use of fewer control rods, less expensive fuel, and more kW from a given fuel load—all of which mean definite economy.

After the primary loop water passes through the reactor, it flows to one of the five steam generators. The flow of water through the reactor is 75m. lb/hr. Each steam generator is 45 ft high, and just less than 10 ft in inside diameter. The heat exchange tubes within will stand in a plate 23 in. thick, and almost 10 ft wide. No plates of these dimensions have ever been produced, but feasibility studies indicate that it can be done.

In each of the steam generators, approximately 900,000 lb/hr of dry and saturated steam is produced. All five funnel through a common header into the secondary loop, which feeds steam to the turbine at a rate of nearly 4½m. lb/hr.

## The Best Rating

Westinghouse selected a 330 MW plant after studying the feasibility of a closed cycle plant at every rating from 5 MW to 400 MW. They found that power costs reduced sharply in the closed cycle plant until 330 MW is reached; then there is a sharp levelling in the curve. This levelling reflects an added capital expenditure needed above 330 MW. At that

(*Continued on page 64*)

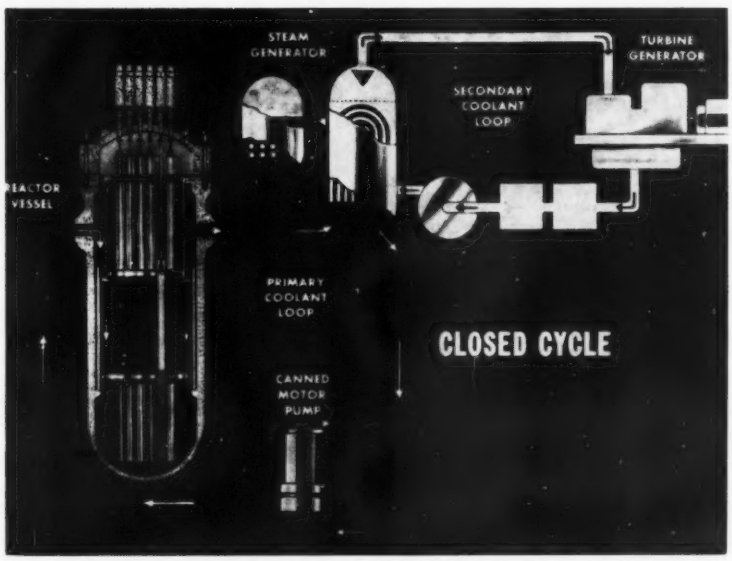



**Fig. 3—A 330 MW plant based on this system would cost $68 m., according to Westinghouse, plus $4.4m. for development**

**330 MW Closed Cycle Plant**

| | |
|---|---|
| *Power Ratings* | |
| Gross electric generator output | 350 MW |
| Plant net electrical output | 330 MW |
| Steam conditions at turbine throttle | 650 lb/sq.in. abs., dry and saturated |
| *Primary System* | |
| Number of heat transfer loops | 5 |
| Normal operating pressure, primary design | 2,150 lb/sq.in. abs. |
| Total reactor flow | $75 \times 10^6$ lb/hr |
| *Reactor Vessel* | |
| Material | Carbon steel with stainless steel clad |
| Design pressure | 2,500 lb/sq.in. abs. |
| Design temperature | 650°F. |
| Overall length of assembled vessel and closure head | 41 ft |
| Inside diameter of vessel shell | 142 in. |
| Thickness of vessel shell (excluding cladding) | *c.* 10 in. |
| Nominal clad thickness | ¼ in. |
| Weight of vessel | 300 tons |
| *Steam Generators* | |
| Number of units | 5 |
| Type | Vertical U-tube with integral steam drum |
| Design pressure, tube side | 2,500 lb/sq.in. abs. |
| Tube material | Stainless steel |
| Overall length | 45 ft |
| Shell, outside diameter | 114 in. |
| Shell, material | Carbon steel |
| Weight | 300,000 lb |
| *Main Coolant Pumps* | |
| Number of units | 5 |
| Type | Vertical, single stage radial flow with bottom suction and horizontal discharge |
| Design capacity | 40,500 gal/min |
| Design pressure | 2,500 lb/sq.in. abs. |
| *Main Coolant Loops* | |
| Number of loops | 5 |
| Main piping and fittings material | Stainless steel |
| Design pressure | 2,500 lb/sq.in. abs. |
| *Thermal and Hydraulic Design of Core* | |
| Coolant flow | $75 \times 10^6$ lb/hr |
| System pressure, design | 2,500 lb/sq.in. abs. |
| *Nuclear Design* | |
| Loading technique | 3 region—3 cycle |
| *Initial U-235 Enrichment, w/o* | |
| Outer region | *c.* 2.9 |
| Middle region | *c.* 2.6 |
| Inner region | *c.* 2.1 |
| *Turbine Generator* | |
| Rated capacity | 330 MW |
| Type | Tandem compound quadruple flow |
| Speed | 1,800 rev/min |
| Stages steam separation | 1 |

## ADVANCED WATER REACTOR SYSTEMS

(*Continued from page 63*)

point, the largest single-shaft, 1,800 rev/min turbine is being used; beyond it, parallel turbines would be necessary.

Further, the economics of the 330 MW turbine are very attractive. It is a highly efficient, 1,800 rev/min, tandem compound turbine with both a high pressure and low pressure unit. Steam enters the high pressure unit at 650 lb/sq.in., passes through this first stage and into a moisture separator, and then on to the low pressure section. The first section is designed for double flow, the second for quadruple flow. Operating on a single shaft with 40-in. exhaust blades, the complete turbine-generator set will be 135 ft long.

The reactor will be contained in a sphere with an overall diameter of 140 ft and walls 1¼ in. thick.

### *Competitive Electricity*

Since the technology behind closed cycle reactors is far advanced, Westinghouse see no serious technical problems in extending the size of the reactor to match this turbine.

This plant is the first all-nuclear power plant to produce electric power on a reasonably competitive mills/kWh basis. Here are the figures, using the same ground rules quoted before: for capital expenditure, 3.3 mills/kWh; fuel, 3.0 mills/kWh; operation and maintenance, 0.5 mills/kWh. Including indirect costs of 0.5 mills/kWh, the total cost/kWh, 7.3 mills.

Summarizing, the integral boiling and superheating reactor is farther away in time than the other plants, and the first one to be built would be a 20 MW prototype plant. Research and development costs would be the big item, costing an estimated $11.3m. Capital cost of the prototype plant itself is estimated at $17m.

### *Taxes, etc. Not Included*

The estimates of costs for each of these plants include all probable expenditures for components and building materials. Naturally, such items as taxes, interest during construction, land, offsite improvements, escalation, and general administrative and overhead charges are not included, since they could not be estimated accurately without reference to a specific contract. However, for convenience here these have been estimated as 0.5 mills/kWh.

The 225 MW combination plant could be built essentially from to-day's technical know-how. There are no major research and development hurdles. This is reflected in the R & D cost, which Westinghouse estimate at $4.5m. The plant itself would cost $45m.

For the third recommended plant, the 330 MW closed cycle plant, a relatively low research and development cost of $4.4m is required. The plant itself will cost $68m., which, in this high rating breaks down to a low capital investment per kWh.

Deciding which of these plants fits the purposes of a specific utility is a difficult task. But the perspective can be established a little better by comparing these three plants on a mills/kWh basis.

The 22 MW prototype integral boiling and superheating plant is not designed to be competitive economically to-day because its principal product will be knowledge and experience, not power. In the long range, this will be the forerunner of a larger economical power plant. Principle reasons for building it now would be to advance the art—and a significant contribution it would be.

The 330 MW plant also has a very promising long-range picture, but at the same time is attractive here and now. The conservative power cost figures for this plant of 7.3 mills/kWh have already been mentioned.

Westinghouse believe that for the next half-century this will in all probability be the most practical nuclear plant in the power industry.

### *Westinghouse Guarantee*

To-day's most economical plants, at an estimated 7.3 mills/kWh, are the 330 MW and the combination plant. In the long range, the combination is subject to higher power costs because of the rising price of fossil fuels.

To go one step further, Westinghouse guarantee the manufacturer's controllable costs: plant capital cost; plant capability; and fuel burnup. Having these guaranteed, the cost of energy to the utility is directly a function of: plant load factor; individual annual charges; and operation and maintenance costs —all of which can be controlled by the operators of the plant.

## *Lighting for TV in Reactor*

THE problem of providing lighting for television cameras on a nuclear-reactor charge machine has recently been investigated experimentally by the Illumination department of the research laboratories of the GEC Ltd., at Wembley. The experiments, carried out in conjunction with the GEC atomic energy division, Erith, formed part of the development work on the charge machine for Hunterston nuclear generating station, which is being built by the company for the South of Scotland Electricity Board. As in other nuclear power stations of this type, changes of uranium fuel in the reactor core will be made without reducing power, and as a result such operations need to be carried out by a special remotely controlled machine. The movements involved will be monitored by instruments on the remote control desk, but it is also desirable for the operator to be able to check the functioning of certain parts visually, particularly in an emergency. This will be done by means of closed-circuit television. The quality of a television picture is dependent on a number of factors, but in particular on the intensity and direction of the object lighting with respect to the camera and on the amounts of light reflected by different parts of the object. Owing to the complexity of the mechanical system and the large number of different operations that had to be considered, the positions of the cameras, and the positions and intensities of the lamps, could not be deduced reliably just by calculation from the drawings. But they had to be determined before fabrication of the pressure vessel for the machine. A full-scale wooden model of the operating mechanisms concerned was built at Erith and re-erected at Wembley for experimental tests. The model was built on its side, for convenience in operation, so that the principal movements were horizontal rather than vertical, and represented the top part of the charge machine, occupying a roughly cubic space of 12 ft side. Operations such as removing and stowing the standpipe door and concrete shield plug, locating the charge tube, inserting and withdrawing fuel elements, could all be simulated by manual operation of parts of the model. In the actual machine, illumination will be by 125w high-pressure mercury-vapour lamps, mounted on the outside of the pressure vessel and shining through glass windows. For the purpose of the experiments a frame representing the pressure-vessel wall was erected and the lamps, mounted on the frame. Tests were then carried out to determine the most suitable positions of lamps and cameras.

# "New" Metals

## RESEARCH AND PRODUCTION by I.C.I. Ltd.

*A small arc furnace in the ICI's research department for preparing buttons of metals for evaluation purposes*

WROUGHT beryllium for the fuel cans to be used in the UKAEA Advanced Gas Cooled Reactor at Windscale is being produced by Imperial Chemical Industries Ltd. They have built a special production plant for the purpose at their Kynoch Works, Witton, Birmingham. The first of its kind in Europe, it is part of the £10½m. facilities ICI have established at Witton for the development and production of "new" metals. These, in addition to beryllium, are titanium and zirconium, the production of which is on a commercial scale, and hafnium, niobium and vanadium, the development of which is still very much in the research stage.

All these "new" metals are of interest to the nuclear engineer—indeed, with the exception of titanium, their utilization is principally in the nuclear field. Titanium, the first of the group to be commercially developed, is chiefly used in the aircraft industry. It has applications in chemical and electro-chemical engineering, and in the nuclear field it is believed that its alloys are suitable for certain reactor components.

### Commonly Used

Zirconium, which was first produced commercially by ICI in 1958, is firmly established as a nuclear structural material. Its alloys are widely used in pressurized and boiling water reactors, both for fuel cladding and various core components. The metal itself is used in sodium cooled reactors, including the fast breeder at Dounreay, for which ICI rolled two tons of zirconium foil. Currently they are preparing a zirconium alloy for the fuel element supports in the Bradwell reactors.

Outside nuclear engineering zirconium has few uses, but they are important. It is used for lined vessels, pump and valve components, agitators, thermocouples and other items of chemical plant, because of its acid resistant qualities, and in the form of shredded foil or fine gauge wire for use in photographic flash bulbs.

### Future Under Trial

Beryllium is of interest to the nuclear engineer because of its high strength at elevated temperatures, good corrosion resistance to carbon dioxide and very low neutron absorption cross-section. It is because of these properties that beryllium is being used in the AGR—magnesium alloys which are suitable as a fuel cladding material in the first-generation gas cooled reactors would be unsuitable where much higher temperatures are involved. The future of beryllium as a cladding material for later stage reactors rests very much on its performance in the Windscale prototype.

Outside the nuclear engineering field beryllium is potentially interesting to aircraft manufacturers. It has in fact, already been used in the United States for components in high-speed aircraft, guided missiles and guidance systems. There are large technical and economical obstacles to overcome, however, before it is used on any widespread scale.

Of the metals still in the research stage at Witton, hafnium has possibilities as reactor control rod material, because of its high neutron capture, while niobium and vanadium are being experimentally tried out as cladding materials in the Dounreay fast reactor.

None of the so-called "new" metals under production at Witton is really new. Both titanium and zirconium have been known for 150 years, while beryllium has for many years been used as an additive in the production of beryllium-copper, a strong alloy widely used in the electrical industry. What is new about these particular materials is their relatively large-scale production in wrought forms.

### Problems to Overcome

They all possess properties which present formidable production problems. They are difficult to extract from their ores and once the metal has been obtained it cannot be melted and turned into massive form by normal methods. The production of beryllium, for instance, involves powder techniques, and to add to the difficulties, beryllium in powdered form is highly toxic. Elaborate

precautions have to be taken, therefore, to protect operatives and scientific staff from the hazards involved. It is the technical difficulties involved that have taken so long to overcome.

### Metals are Expensive

Because of the processing difficulties the intial cost of these materials is, naturally enough, high. Raw beryllium costs £20/lb; current quoted world price for the wrought metal is £160/lb. With technical improvements and an increase in its demand this price should eventually be reduced, as it was in the case of titanium.

In the natural state, titanium is a fairly abundant metal. It is, however, difficult to extract from its ores, the principal ones being ilmenite, an oxide of iron and titanium, and rutile titanium dioxide. The ore has first to be converted to titanium tetrachloride which is then reacted with another metal to produce titanium. The first commercial extraction process to be introduced—the Kroll process—is based on the reaction of titanium tetrachloride with magnesium. Titanium mixed with magnesium chloride is produced, and is removed by distillation under vacuum.

A better and cheaper process is the sodium reduction method which ICI developed and on which their full-scale titanium production plant at Middlesbrough is based. Design output of this plant is 1,500 tons a year.

### Melting a Difficulty

Titanium cannot be turned into massive form by normal casting methods. It has a very high melting point—nearly 1,700°C., or 200°C. higher than that of steel. This would not be an insuperable problem, however, if, in its molten state, titanium did not combine with any of the materials normally used to make or line a high-temperature furnace. Moreover, molten titanium absorbs gases, notably oxygen and hydrogen, which affect its physical properties and lessen its usefulness as a structural material.

These difficulties are overcome by melting the titanium in an electrode vacuum furnace. Titanium granules from the production plant are compressed into semicircular briquettes which are welded together to form a one ton, 12 ft long cylindrical electrode. Sometimes other powdered metals are mixed with the titanium granules to form alloys.

The 12 ft titanium electrode is then suspended from inside a furnace, at the bottom of which is a water cooled crucible. The furnace is evacuated and an arc struck on a small quantity of titanium powder in the crucible base. The electrode is slowly melted to form an ingot in the crucible. To ensure complete homogeneity the process is repeated. The ingot is raised to the top of the furnace and re-melted into a larger-diameter crucible.

### 20,000 Tons a Year

There are three furnaces in operation at the Kynoch works with a total design output of 20,000 tons a year. Because titanium melting is subjected to hazards not encountered with more conventional metals all operations are carried out by remote control. Each furnace is built inside a massive 60 ft high reinforced-concrete cubicle, and before melting starts this is sealed by means of a 10 ton door, so that even in an emergency there is no risk to plant personnel. An optical arrangement enables operators to see into the furnace while it is in operation with complete safety.

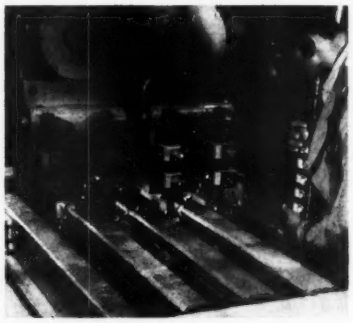
**Machining an ingot of titanium before it is sent to the forging department**

Once titanium has been consolidated into ingot form, conventional working techniques can be used, provided that attention is paid to the metal's particular characteristics, such as its oxidation behaviour, low rate of hardening and tendency to gall on sliding contact.

When ultrasonic testing has checked freedom from flaws the ingot goes to the forge for forming into flat slab or round billet. It is heated in an electric furnace and then forged by press or hammer. Shotblasting removes the dull layer of the forged product giving it the characteristic silvery sheen of the wrought metal.

Most of the titanium produced at Witton goes to the ICI fabrication plant at Waunarlwydd, near Swansea, where it is rolled or extruded to form rod, sheet, tube, wire and sections.

Zirconium presents very similar difficulties to those encountered in the production of titanium. With nine years' research, development and production experience behind them ICI had little difficulty in achieving commercial production of the wrought metal. First commercial yield was in fact in 1958.



**Light surface machining of forged titanium bars before being rolled into rod**

### A "Sponge" is Produced

Like titanium, zirconium is difficult to extract from its ore. Silicate zircon is found in beach sands the world over and zirconium in sponge form is extracted from this by a chemical reduction process. One complication in these processes is that a sister-metal, hafnium, occurs naturally to the extent of one or two per cent. in all zircon deposits; because hafnium readily absorbs neutrons it has to be separated from the low neutron absorber zirconium when the latter is to be used in a nuclear reactor. This is done in the course of the extraction process and it produces " reactor grade " sponge.

Zirconium sponge is treated in a similar way as titanium granules, being melted in an electrode arc vacuum furnace. Ingots weighing up to three tons are produced in this way.

The ingots are converted into wrought forms—strip, sheet, plate, rod, tube and wire—by conventional processes, though precautions have to be taken to avoid contamination during hot working and annealing, particularly by nitrogen, which impairs corrosion resistance.

Beryllium presents quite different problems in its processing. The principal source of this metal is beryl, an aluminium beryllium silicate generally yielding about 3½ per cent. beryllium. No economic concentration process has yet been developed and the beryl crystals are sorted by hand.

### Beryllium Extraction

Metallic beryllium is separated by a three stage extraction process. The ore is converted into beryllium hydroxide, and this in turn into beryllium fluoride or beryllium chloride. Raw metal is extracted either by reacting the fluoride with magnesium to produce "pebble" beryllium, or by electrolysis of a mixture of beryllium chloride and sodium chloride, to yield "flake." The ICI plant uses both "pebble" and "flake" as its raw material.

Two factors complicate the consolidation of the raw beryllium. First, properties of the wrought metal are adversely affected by impurities in the raw metal, so that refining in a vacuum induction melting furnace is essential. Second, even vacuum cast beryllium has a very large grain size and is extremely brittle. If metal with superior mechanical properties is to be produced powder metallurgy techniques must be used. The cast ingot is therefore machined to swarf which in turn is ground to a fine powder.

The powder is packed into graphite moulds and sintered at a high temperature under vacunm. The solid compacts that result from this process are then either machined to finished size or prepared for further processing.

Rod and tube are produced by extrusion. To avoid seizing of the beryllium in the dies the extrusion slugs are electro-plated. The plating is removed after the process.

Because of the high toxicity of beryllium powder elaborate precautions have to be taken to prevent operatives coming into contact with it. All parts of the plant where beryllium is handled are air conditioned and all personnel working in the plant have to make a complete change of clothing before both entering and leaving. All machining operations are carried out in glove boxes from which the air is automatically removed and staff have to wear special protective clothing for certain maintenance operations.

### Reducing Hazards

The air conditioning is so designed that contamination of the air in the plant is never more than two micrograms of beryllium dust/cu.m—the level considered safe by the UKAEA and U.S. Atomic Energy Commission. Air is changed every 3 min so that about 200 tons of air are moved every hour and passed through absolute filters before being discharged into the atmosphere through a 150 ft chimney. The level of contamination of this air is even less than permitted within the working area—0.01 micrograms/cu.m.

Sealing compound is used between all wall and ceiling joints and a negative pressure is created inside the building to ensure that all air follows the prescribed route through the exhaust filters and so keep adjacent areas free from possible contamination. Flat ledges are kept to a minimum and to facilitate cleaning, floors are curved to the walls and all surfaces are smooth and painted.

Access to the plant is normally only through the changing rooms where personnel are supplied with a complete set of clean clothing and where there are toilet facilities.

### Non-Pyrophoric

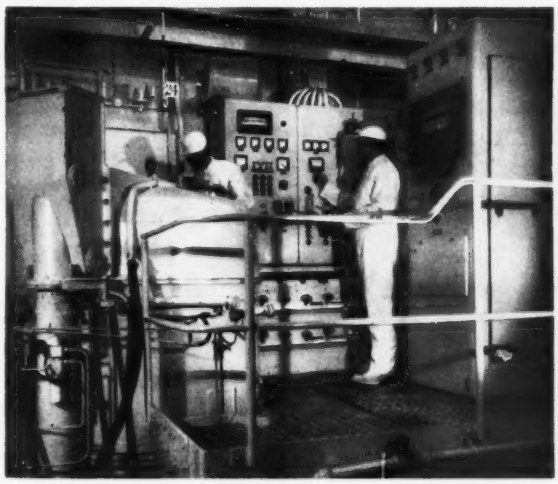
Unlike most finely divided metallic powders beryllium is not pyrophoric. Since a fire in the plant could interfere with the air conditioning, however, constructional materials and finishes throughout have been selected to reduce the fire risk to a minimum.

To ensure that strictest standards of purity are maintained air samples are taken at regular intervals both inside and outside the building plant. The samples, some 3,000 a week, are sent by pneumatic tube to a testing laboratory.

Rooms housing electrical equipment, boilers and ancillary equipment are situated outside the air conditioned zone and services to the plant are so arranged to facilitate easy maintenance.

The plant, which has an initial design output of seven tons a year, cost about £1m. to build. Some 200 operatives, technicians and scientists are employed in it.

None of these metals could have been put into full-scale production



**Beryllium powder is consolidated into a sintering furnace before extrusion**

**Swarthing lathe for reducing ingots of beryllium to chips**

without the backing of intensive research and development and at Witton ICI have extensive laboratories solely designed for this purpose. Titanium, zirconium and beryllium have of course outgrown the status of "research projects." Even so they still entail work for these laboratories, in addition to the metals as yet unharnessed for commercial production.

The work of the research department, which employs some 300 people, can be broadly divided into two classifications—work which supports the production department and, secondly long term research. Under the first heading comes work designed to ensure that the quality of the manufactured products is maintained and possibly improved. Ways of increasing the efficiency of manufacturing processes also have to be investigated.

Under the second heading the department has to obtain new evidence and data on the behaviour of metals and alloys not only of the established products but also of those which are not yet in production such as hafnium, niobium and vanadium.

The department is divided into various sections, each with its own particular function and range of work. One job of the analytical section, for instance, is to devise means of determining the composition of reactor grade zirconium alloys. This involves testing for no fewer than 28 elements, certain of which must not exceed one part in 2m. Another job of this section is to analyse the air samples from the beryllium plant.

In the corrosion section every batch of zirconium supplied for nuclear engineering applications is tested to ensure that its behaviour in corrosive conditions will satisfy the exacting specifications.

## For N-Applications

Although the department has been concerned for many years with research into new metals and alloys it has only recently set up the new metals section, the nucleus of which was established for pioneer work on titanium and zirconium. To-day the section is much concerned with metals likely to play an important part in nuclear engineering.

The evaluation procedure to which new metals are subjected is prolonged and comprehensive.

Evaluation is carried out initially on very small buttons, weighing perhaps as little as $\frac{1}{2}$ oz, produced in special miniature furnaces. Some metals will only develop homogeneous structures if heated for very long periods. At the other extreme they may undergo undesirable structural changes if allowed to cool naturally, so special treatment in vacuum quenching furnaces may be needed before the specimen is ready for microscopic examination.

When results are satisfactory, progressively larger melts are processed in various types of vacuum furnace. The arc melting laboratory has facilities for producing buttons weighing up to 100 gm and ingots weighing from 5 lb to 300 lb. At every stage the metal is subjected to exhaustive chemical, physical and mechanical testing, its deformation characteristics are studied so that suitable rolling extrusion, drawing techniques can be established and close attention is paid to any problems relating to machining and jointing the wrought product.

**High sensitivity machines testing creep properties of zirconium**

Hafnium, niobium and vanadium are all being evaluated in this way by ICI at Witton. The latter two metals are already being tested in the Fast Breeder at Dounreay.

With their "new" metals programme at Witton, ICI once again demonstrate their leadership in the field of nuclear materials. It was ICI who made the first extruded uranium rod to be produced in Britain, in 1942. Since then many great technological advances in nuclear engineering have been and are still being made. ICI keep abreast with this ever moving progress.

**PHYSICAL PROPERTIES OF THE "NEW" METALS AND OTHERS**

| | Be. | Mg. | Zr. | Al. | Fe. | Cu. | Ti. |
|---|---|---|---|---|---|---|---|
| Atomic number | 4 | 12 | 40 | 13 | 26 | 29 | 22 |
| Atomic weight | 9.02 | 24.32 | 91.2 | 26.97 | 55.85 | 63.54 | 47.90 |
| Melting point (°C.) | 1283 | 650 | 1852 | 660 | 1535 | 1084 | 1660 |
| Density (g/cm³) | 1.85 | 1.74 | 6.51 | 2.70 | 7.86 | 8.94 | 4.51 |
| (lb/in.³) | 0.066 | 0.063 | 0.235 | 0.097 | 0.283 | 0.322 | 0.163 |
| Thermal conductivity at 20°C. (cal/cm/°C./sec) | 0.36 | 0.35 | 0.05 | 0.50 | 0.17 | 0.92 | 0.04 |
| Thermal neutron absorption cross-section | | | | | | | |
| Microscopic (barn*/atom) | 0.009 | 0.059 | 0.180 | 0.215 | 2.53 | 3.69 | 5.6 |
| Macroscopic ($cm^{-1}$) | 0.0012 | 0.003 | 0.008 | 0.014 | 0.215 | 0.313 | 0.328 |
| Macroscopic comparison (Be. as 1) | 1 | 2.5 | 7 | 12 | 180 | 260 | 273 |
| Specific heat (0—100°C.) cal/g/°C.) | 0.42 | 0.245 | 0.066 | 0.211 | 0.109 | 0.093 | 0.126 |
| Coefficient of linear expansion (0—100°C.) ($\times 10^{-6}$ per °C.) | 11.54 | 25.8 | 5.8 | 23.8 | 11.9 | 16.4 | 8.9 |
| Modulus of elasticity ($\times 10^6$lb/in.²) | 43 | 6.5 | 13.7 | 9.7 | 29 | 17.5 | 15 |

*1 barn = $10^{-24}$ cm²

# Design of Large Gas Ducts*

by A. T. BOWDEN, BSc, PhD, and J. C. DRUMM, BE

(*Continued from page 43*)

AT the station being built at Bradwell, each of the two reactors supplies heat to six heat exchangers which are set with their centres on two parallel lines about 90 ft from the centre of the reactor pressure vessel. Hot gas leaving the core passes through a 60 in. bore duct to the top of each of the heat exchangers, flows downward in cross flow over a large number of tube banks which lower its temperature from 390°C. to 174°C. at the exit from the economizer tube nest in the base of the heat-exchanger shell. The gas is then drawn into a single-stage axial-flow blower which raises the pressure of the gas by 7.6 lb/sq.in. and forces it to return to the inlet of the reactor pressure vessel.

### One Plane Simplifies

Differential thermal expansion of the ductwork and the vessels which it connects is absorbed by the lateral flexure of three tied bellows joints in each major line of ducting. The centre of the reactor vessel, the centre line of each heat exchanger and that of the ducts which connect them together, lie in the same plane. Thus all the differential expansion associated with each heat exchanger circuit takes place in one plane and no provision need be made for thermal movements at right angles to this plane. This feature permits the adoption of a simple flexible tongue as a means of transferring across the bellows the large axial pull in the duct due to the internal gas pressure.

Fig. 1 shows an outline of a typical gas circuit. The positions of the three bellows in the top and bottom duct lines can be seen. The bends in each line of ducting are equipped with a cascade of vanes designed to turn the gas round the corner with a minimum of pressure loss.

### Hangers Take Weight

The weight of the ducts is taken on a number of spring hangers of the constant support type. These hangers take the full weight of the ductwork with a variation in effort of less than ±5 per cent. over their designed range of movement.

The short length of ducting between the heat-exchanger outlet and the blower inlet contains an untied expansion bellows. There is a compensating bellows connecting the bottom of the blower casing to a dished-end mounted in a strong cradle which is grouted into the foundation concrete. This ensures that the gas-pressure force of about 200 tons is transferred directly to earth and not through the support palms of the circulator body.

A 36 in. bore duct runs from the side of the heat-exchanger shell to join the bottom 60 in. duct. This duct provides a by-pass which protects the blower against stalling and overheating when it is started up with the valves in the main circuit closed. Differential expansions in this duct are absorbed also by means of three tied bellows joints.

### Valves Isolate

In each circuit quick-closing butterfly valves are placed in the top and bottom duct lines as close to the reactor as possible. These valves are capable of being shut in tens and are designed to give almost leak-tight closure under a differential pressure of 147 lb/sq.in. They provide the means of isolating an individual circuit either for servicing or under the emergency conditions associated with a serious leak either in a boiler tube or in the gas pressure circuit.

All flanges in the ductwork are of the forged neck-weld type. Gas tightness is ensured by seal-welding projections on the mating faces of the flanges. The design of the flanges is based on the well-known Taylor-Forge method. Normally the proportions of neck-weld flanges are chosen on the basis of permissible stress in the flange neck. Where large-diameter flanges are used on comparatively thin-walled ducts it is also necessary to limit the flexibility of the flange in order to reduce the danger of seal-weld cracking due to flexure of the joint as the pressure level in the ducts is altered.

### Cold Drawing Used

At Bradwell the 60 in. bore flanges are proportioned so that the stress in the flange neck is 5 ton/sq.in., and the flange tilt under pressure is 0.002 rad. The design bolt stress is 5 ton/sq.in. The bolts are tightened to their correct tension by means of torque spanners.

Cold drawing is used in each line in order to reduce the stress level in the bellows and the magnitude of the duct reactions. The amount of cold drawing was selected so that throughout the 20 years life of the plant the total cold-condition stresses due to pressure and to deflection are less than the cold yield strength of the bellows steel. In selecting the cold draw for the reactor outlet ducts it was recognized that bellows steels suffer a certain amount of relaxation when subject to stress for prolonged periods at 390°C. This relaxation depends on the total stress in the bellows wall (pressure stress and deflection stress) and leads to a reduction with time of the deflection stress in the hot condition. The

*From a paper, "The Design and Testing of Large Gas Ducts," presented to the Institution of Mechanical Engineers.

relaxed stress reappears, of course, with the opposite sign in the cold condition. It was assumed in the Bradwell design that the whole of the working condition deflection stress in the reactor outlet duct bellows will be relaxed.

### Reduced Stress

Fig. 2 shows a thrust diagram for the duct system. The low magnitude of the thrusts and moments applied to the reactor pressure vessel will be noted. Using the Kellogg expression given above for bending stress at nozzles the additional stresses in the vessel wall due to the moment applied by the top ducts in the hot and cold conditions are only 185 lb/sq.in. and 73 lb/sq.in. respectively. Similarly the greatest additional stress due to the duct moment at the reactor inlet nozzle is only 1,250 lb/sq.in. as compared with a permissible stress of about 4,000 lb/sq.in.

At Bradwell the various duct components are delivered to site with their ends sealed off with waterproof transport covers. The inside surfaces are clean and painted with a colloidal graphite protective coating. Before delivery to site each section of duct and each valve and bellows has been pressure tested at the makers' works to 270.5 lb/sq.in.

Prior to erection of any duct components a system of vertical and horizontal centre lines is set out in each duct cavity. By means of these centre lines a carefully detailed erection procedure it is expected that when erection is complete no item of ducting will be more than $\frac{1}{2}$ in. away from its correct position and that errors in the orientation of the bellows tongues will not exceed 15 min of arc. Errors accumulated during erection will be taken up at the template lengths provided in each line of ducting.

### Stress-Relieving Procedure

It was agreed with the surveyors that shop welds on ducting on the heat exchanger side of the main valves would not be stress-relieved but that shop-welds on the reactor side of these valves would be stress-relieved together with all site welds in the pressure circuit. Site stress-relief of welds is being carried out by means of local heating mats wrapped round the weld junction. A continuous record is made of metal temperatures during the heating, stress-relieving and cooling periods. The temperature-recording instrument also acts as a controller for the heaters and can be preset to carry out any heating and cooling cycle desired.

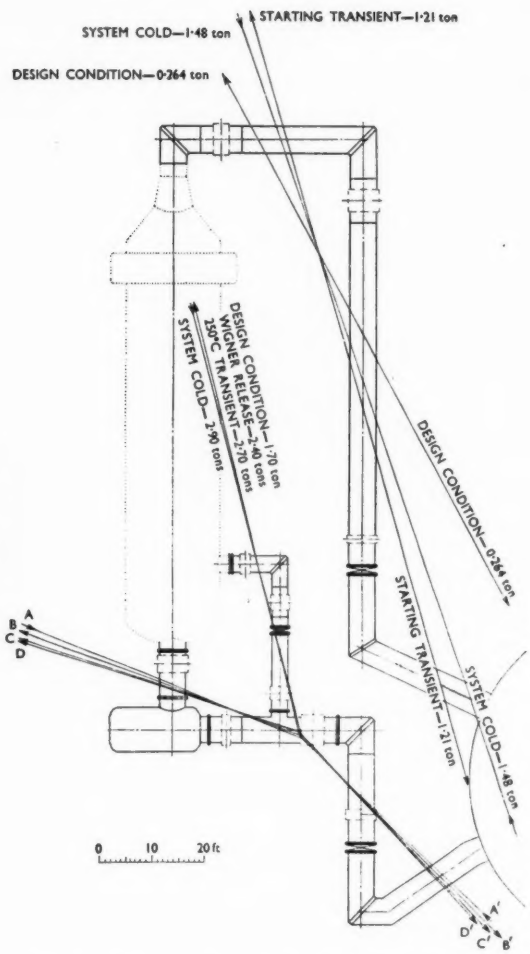



**Fig. 2—Duct thrusts due to thermal expansions. System cold. A=4.13 tons. A′=6.36 tons. 250°C. transient temperature. B=3.28 tons. B′=5.35 tons. Wigner release. C=2.75 tons. C′=4.52 tons. Design condition D=1.74 tons. D′=3.02 tons**

Some site welds occur in close proximity to valves and bellows and in order to reduce the severity of the thermal gradients across these items it was decided to raise their temperature levels to around 400°C. by means of internal heaters before bringing the weld junctions up to 500/550°C. with external heaters. On future stations it is intended to place site welds sufficiently far away from all sensitive equipment to obviate the need for general heating prior to commencing stress relief of the site weld junctions.

On completion of the erection of the gas pressure circuit for a reactor the whole system will be air tested to a pressure of 190 lb/sq.in. and checked for leaks. Care has been taken in the design of the pressure circuit to reduce to a minimum potential sources of leakage. All flanged joints are seal welded, there are no large steel castings in the circuit, and all small valves and even some instruments are welded directly into their lines. Each line of small-bore carbon dioxide pipe is separately pressure tested and checked for leaks immediately after connection to the main gas circuit. This practice will greatly reduce the amount of time spent searching for leaks when the whole system is pressurized.

### The Bradwell Bellows

As bellows joints are critically important items in the duct systems being used on gas-cooled reactors it is proposed to give a brief account of the considerations involved in their design and to describe the bellows adopted for Bradwell.

The design of a tied bellows joint falls naturally into two parts: the

design of the bellows convolutions which form the gas seal and the design of the tie which transfers across the bellows the large axial pull in the ducts due to the internal gas pressure. The tie may also be required to protect the bellows convolutions from transverse forces in cases where the layout of the duct system and the stress level in the convolutions make this necessary.

### Different Shapes

The majority of bellows designs put forward for use on reactor gas ducts involve the use of U-shape convolutions. The sides of the U are generally left parallel though some makers shorten the overall length of the unit by collapsing the sides of the U inward. This device also brings about a small reduction in the stresses in the convolution wall due to pressure though gain is probably cancelled in part by an increase in the stresses due to deflection.

Toroidal-shaped convolutions are subject to very much lower pressure stresses but higher deflection stresses than comparable U-shape convolutions. However, toroidal bellows are expensive to fabricate to designs which permit full X-ray of all welds and their use is not justified for the pressure levels prevailing in present-day gas-cooled reactors.

In the case of U-shape convolutions with a small ratio of height to mean bellows radius and a ratio of peak radius to convolution height which is constant and less than 0.25 the following relations are obeyed approximately:

$$f_p \propto \left(\frac{h}{t}\right)^2$$

$$f_d \propto \left(\frac{t}{h}\right)^2 \times \frac{1}{t}$$

$$S \propto \left(\frac{t}{h}\right)^3$$

where $f_p$ is the stress in the convolution due to pressure, $f_d$ is the stress in the convolution due to deflection, $S$ is the stiffness of the convolution, $t$ is the mean thickness of the convolution wall, and $2h$ is the mean height of the convolution. (Wall centre at outer peak to wall centre at inner peak.)

### Advantages of U-Shape

Thus, if the wall thickness of a bellows is doubled and at the same time the height of the convolution is doubled, the bending stress in the convolution due to pressure remains unaltered and the stiffness of the bellows is also unchanged. On the other hand, however, the stresses due to a given deflection per convolution are halved.

Within the limits of what it is possible to roll increasing the height and wall thickness of U-shape convolutions is advantageous in that it leads to a reduction in the stresses in the bellows wall. A further advantage attached to the use of high rather than low convolutions lies in the reduction in hoop stress due to pressure. This can be quite important where large-diameter bellows are under consideration especially when the plant insurers insist that a prototype unit be capable of withstanding a test pressure equal to four times the design pressure.

The Bradwell bellows convolutions are U-shape and made from $\frac{1}{4}$ in. thick molybdenum-vanadium steel. Each convolution has a mean height of $4\frac{1}{2}$ in. and is formed by pressing two strips of plate into channels, rolling each channel into a half circle and butt welding the half circles together to form a complete convolution. A number of convolutions are then welded together to form a group of the required size. The end convolutions of the group are welded to two short lengths of $1\frac{1}{4}$ in. thick duct and the complete unit is placed in a controlled atmosphere furnace for normalizing and tempering. All welds are X-rayed and made to the Class I requirements of Lloyd's Register.

### Designer's Problems

One of the principal difficulties confronting a designer of bellows is that of making a correct selection of the basis on which to stress a design. Considerations of economy, space limitation and the need for flexibility generally make it inevitable that bellows be highly stressed compared with the conventional parts of a duct system which are designed to Code stresses. The majority of manufacturers of thin-walled commercial bellows recommend their products as being suitable for service under conditions so severe that their materials are subject to stresses which bring them well into the plastic range. Design is on the empirical basis of the proven fatigue life of one or more prototypes of the particular type of bellows.

Reasonable assurance of satisfactory performance is obtained from the use of a safety factor ranging from 2 to 10 or more, based on the expected number of cycles to be endured in operation. The good service obtained from the vast majority of commercial bellows is proof of the success of this design basis. However, the use of very high stress does make a bellows sensitive to small variations in workmanship, heat treatment, and material quality. The risk of failure from these causes is considered to be sufficiently high to give rise to serious doubt about the suitability for reactor service of bellows stressed to the levels frequently used in thin-walled bellows for conventional plant.

### Failure Chance Reduced

The chance of a bellows failure is reduced considerably by combining with the fatigue life basis of design the principle that the total stress in the convolution wall should not exceed a definite level. The level chosen is the 0.5 per cent. proof strength or the yield point of the material. The value of the applied stress is obtained by calculation, using formulae with empirical constants derived from strain gauge tests on the particular type of convolution under consideration.

The use of the design criterion that stresses should not exceed the yield strength of the material brings bellows partly into line with conventional parts of the pressure circuit which are designed to the low average stresses specified in the Codes. Although these average stresses are only equal to about 60 per cent. of the yield strength of the material, local stresses at points of stress concentration, say, around compensated holes, are usually equal to the yield strength of the material.

Owing to the cyclic nature of the stresses imposed on a bellows the use of lower stresses than are common in the normal commercial product does not relieve the designer of the need to eliminate, in so far as it is possible, all causes of stress concentration. For example, longitudinal welds must be ground smooth inside and outside and the use of a circumferential weld at the highly stressed outer peak of a convolution should be avoided. A circumferential weld at the root of the convolution cannot be avoided when bellows

units are made up from individual convolutions.

For the type of bellows used at Bradwell, flexure stresses are substantially lower at the root of the convolution than at the peak so that the presence of a weld in this region does not seriously reduce the fatigue life of the bellows. Close control of

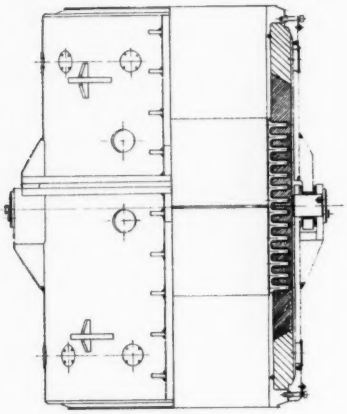


**Fig. 3—Hinged expansion bellows**

material quality and the use of the best possible welding techniques, combined with X-ray of all welds and magnetic or chemical crack detection of welds after final stress relief of the unit, are all necessary if the probability of failure is to be reduced to the low level necessary to protect station personnel and to ensure that an expensive plant is not kept out of commission for the replacement of fractured bellows.

## Connections Important

Most commercial bellows joints are designed for situations where the gas pressure force to be transferred across the joint is small either because the pressure is low or the bore of the bellows is small. The major portion of the design effort is devoted to the convolutions and little thought need be given to the tying arrangements. Bellows joints for gas-cooled reactors involve a combination of large diameter and fairly high pressure, which combine to produce end loads ranging from 220 tons on the Bradwell bellows to around 550 tons on bellows for the latest designs of nuclear stations. These large forces must be transferred across the bellows by some device which is absolutely reliable, which does not give rise to a large resisting moment and which preferably does not require any lubrication or maintenance for its twenty-year life.

The layout of the Calder Hall station necessitated the use of a combination of hinged and gimbal bellows. Fig. 3 shows a section of one of the 54 in. hinged bellows at this station. The salient feature of this design is the use of two cylindrical skirts to achieve circumferential distribution of the concentrated loads at the hinges before these loads are transferred to the wall of the duct through the interlocking pairs of flanges at each end of the unit. The heavy reinforcing rings in the region of the hinges are needed to prevent excessive tilting of the hinges

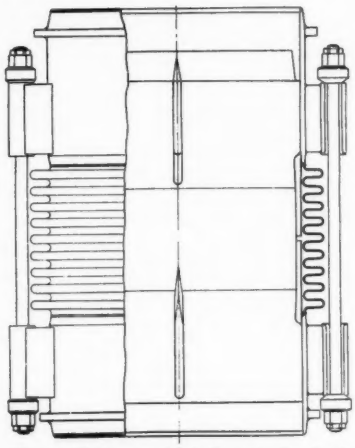


**Fig. 4—Tied expansion bellows for Bradwell**

which could lead to high friction and eventual seizure. The hinges are lubricated with molybdenum-disulphide grease after assembly, and nipples are provided for occasional lubrication in service.

This type of construction was not adopted for the Bradwell bellows because it was considered to have limited development prospects owing to its high cost and the tendency of this cost to increase rapidly with size. The design chosen incorporates a simple flexible tongue, the ends of which are welded into the adjacent ducts. A central cross brace is provided at each end of the tongue to ensure that the tongue remains plane when flexed. In order to provide protection against the catastrophic consequences of a tongue failure under pressure each bellows unit has two tie rods attached to brackets at each end of the unit. These bars are normally unstressed but they are designed to take full gas force in the event of a sudden brittle failure of the tongue. Their proportions have been so chosen that they dissipate by slight yielding the work done by the gas force. This device substantially reduces the stresses in the stiff brackets to which the bars are attached. Fig. 4 shows the main features of the Bradwell bellows.

## Hinges Unnecessary

A disadvantage associated with the use of a tongue for tying a bellows is that the joint has no fixed centre of rotation. This does not lead to any difficulties where the bellows joint is deflected purely by a couple with no shear-type force at right angles to the plane of the tongue. Shear forces can impose large extra deflection stresses on a bellows. These stresses are highest for the convolutions at each end of the bellows and are additive algebraically to any existing stresses in these convolutions due to rotation of the joint. This difficulty with shear forces can easily be overcome by the addition of a pair of

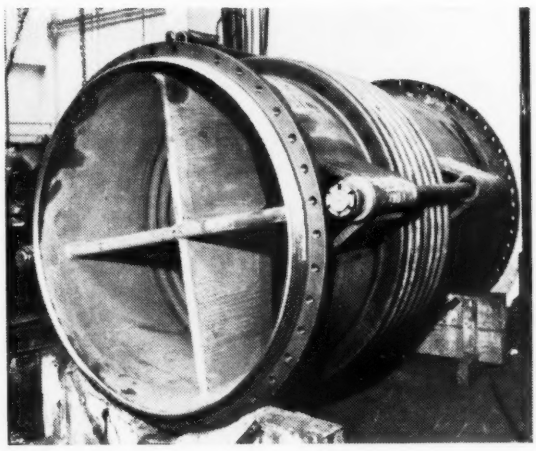


**Fig. 5—Completed bellows for Bradwell**

light hinges on the centre line of the bellows. These hinges do not carry any axial load but are subject to a small lateral load which at Bradwell would not exceed 5 tons. The effect of shear forces is very small in the majority of bellows at Bradwell and hinges are unnecessary. In the three joints where they could be used with advantage it was decided that on balance it was cheaper to use a somewhat larger number of convolutions than to equip a small number of bellows with hinges.

## Trials with Models

The final design adopted for the Bradwell bellows tongues was chosen after a number of tensile and bending tests had been carried out on tenth-scale models. These model tests showed that longitudinal tension in the tongue gave rise to an area of severe stress concentration in the region of the inboard ends of the

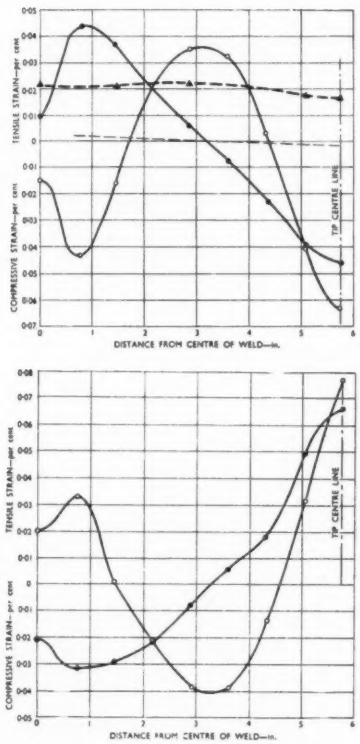



Fig. 7—Graphs made from readings of radial strain on the external (*top graph*) and internal (*lower graph*) surfaces of a convolution. Key —○— radial strain due to pressure, — — △ — — circumferential strain due to pressure, ——●—— radial strain due to tilt, — — — — — estimated circumferential strain due to tilt

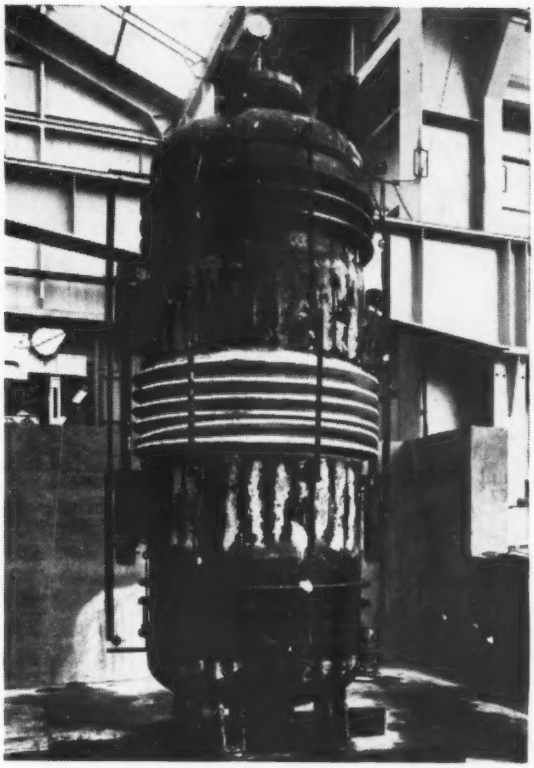


Fig. 6—The bellows test rig built to prove the suitability of the bellows designed for Bradwell

welds which connect the tongue to the duct wall. It was decided to reduce the magnitude of the local stress peak in this region by using $2\frac{1}{2}$ in. thick plate with a central flexible portion which is machined down to $1\frac{1}{2}$ in. thickness. Peak bending stresses occur at the ends of the flexible length. It will be noticed from Fig. 4 that these ends have been kept well inboard of the areas of stress concentration close to the tongue welds. The 2 in. thick braces at each end of the tongue ensure that the tongue remains plane when fixed. They also transfer to the duct wall a portion of the longitudinal pull in the tongue.

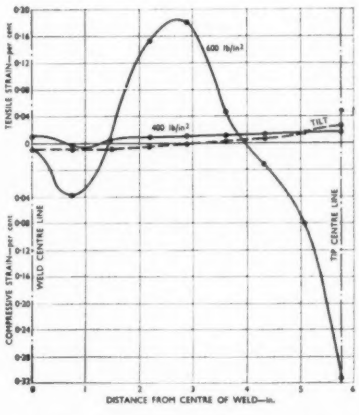



Fig. 8—Distribution of residual strains in convolution after release of pressure

## Photo-elastic Test

Strain gauge readings taken during a pressure test on a prototype 60 in. bellows to four times design pressure indicated that the magnitude of the stress concentration factor at the weld ends was 7 based on the average tensile stress across a section of the tongue end. Approximately the same factor was obtained from a photo-elastic test carried out on a model of the tongue. At one time it was hoped that by suitably profiling the edge of the tongue it would be possible to reduce this high stress concentration factor. However, a series of ten tests on models with different fillet radii showed that a substantial reduction in the stress concentration factor could not be achieved along these lines.

In the paper on which this article is based, the authors acknowledge C. A. Parsons & Co., Ltd. for permission to make use of the detailed information.

# Experimental Studies of NATURAL CIRCULATION BOILING*

## THEIR APPLICATION TO BOILING WATER REACTOR PERFORMANCE

by

P. A. Lottes, J. F. Marchatevve, R. Viskanta, J. A. Thie, M. Petvick,

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DURING the initial design stages of the Experimental Boiling Water Reactor at the Argonne National Laboratory, there was little information that could be used to calculate steam volume fraction as a function of reactor power. The first laboratory experiments were therefore directed at measuring steam volume fraction as a function of power for a channel that closely resembled the proposed EBWR design.

Some initial tests were run at atmospheric pressure. Simultaneously other apparatus were designed to cover higher pressures. Each of the experiments was designed to give specific information. Items 1-6 in Table I list each apparatus tested, and show the type of information desired. Useful information from these experiments is given in the figures of this article.

### *Visual Study Tests*

The visual study apparatus tests were conducted to determine the effect of various additives on the natural circulation flow rate during boiling at atmospheric pressure. The studies covered the following conditions:—

1. Pure distilled water.
2. 2 per cent. acetic acid by volume in distilled water.
3. 10 per cent. acetic acid by volume in distilled water.
4. Dow-Corning antifoam solution in distilled water.
5. Dow-Corning solution: the above plus addition of perfluorocaproic acid (wetting agent).
6. Various concentrations of caustic soda.

The results (Fig. 1) showed little effect of additives on the natural circulation flow rate.

The purpose of the atmospheric boiler was to demonstrate the feasibility of boiling water reactors by

**Table I.—Experimental Systems Designed to Provide Data Applicable to the EBWR at Argonne**

| Apparatus | Number of Channels and Geometry | Maximum Power Density, kW/litre | Maximum Inlet Velocity, ft/sec | Type of Information |
|---|---|---|---|---|
| Visual study apparatus (atmospheric) | 3 annuli, $^1/_{16}$ in. × $\frac{1}{2}$ in. i.d. × 36 in., $\frac{1}{8}$ in. × $\frac{1}{2}$ n. i.d. × 36 in., $\frac{1}{4}$ in. × $\frac{1}{2}$ in. i.d. × 36 in. | 60 | 2.8 | Effect of *p*H and surface tension on circulation rate. |
| Atmospheric boiler | 4 to 20 rectangular, $\frac{1}{8}$ in. to $\frac{1}{2}$ in. × 5 in. × 9 in. to 24 in. | 110 | — | Maximum power and steam volume fraction *vs.* power. |
| 260 lb/sq.in. abs. multi-channel boiler | 6 rectangular, $3^7/_{16}$ in. × $\frac{1}{2}$ in. × 60 in. | 50 | 3 | Steam volume fraction *vs.* power and slip ratio. |
| 260 lb/sq.in. abs. single-channel boiler | Single, rectangular, $3^7/_{16}$ in. × $\frac{1}{2}$ in. × 60 in. | 60 | 3 | Steam volume fraction *vs.* power and slip ratio. |
| 600 lb/sq.in. abs. multi-channel boiler | 3 rectangular, $^7/_{16}$ in. × $4\frac{1}{4}$ in. × 48 in.; 3 rectangular, $^7/_{16}$ in. × $4\frac{1}{4}$ in. × 24 in. | 50 | 1.8 | EBWR design point conditions; steam volume fraction *vs.* power. |
| 600 lb/sq.in. abs. single-channel boiler | Single, rectangular, $\frac{1}{2}$ in. × 2 in. × 60 in.; single, rectangular, $\frac{1}{4}$ in. × 2 in. × 60 in. | 50<br>100 | 3.0<br>3.4 | Boiling friction factors, slip ratios. |
| Atmospheric air-water loop | Single, rectangular channels, 4 ft long × 2 in. wide with spacings of $\frac{1}{8}$ in., $\frac{1}{4}$ in., $\frac{1}{2}$ in., $\frac{3}{4}$ in. and 1 in. | 0 | 10 | Effect of flow area change on density, and pressure drop studies. |
| 2,500 lb/sq.in. abs. single-channel boiler | Single, circular, 1 in. i.d. × 48 in.* | | 10 | Natural circulation performance. |

*2,000 kW/litre available, maximum of 300 kW/litre run so far.

*Paper presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958.

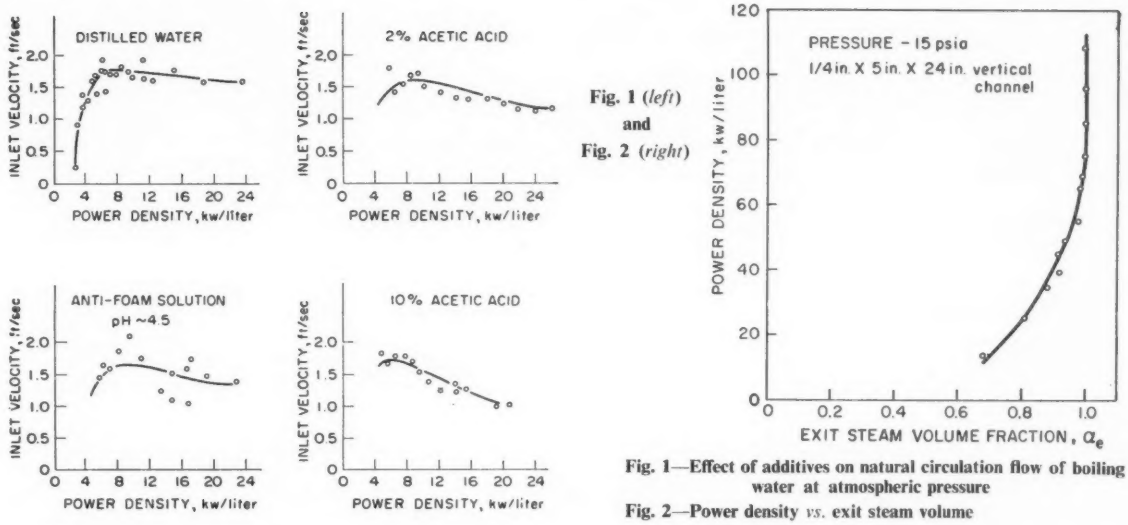



Fig. 1 (*left*) and Fig. 2 (*right*)

**Fig. 1—Effect of additives on natural circulation flow of boiling water at atmospheric pressure**

**Fig. 2—Power density *vs.* exit steam volume**

first showing that useful amounts of steam could be generated at low pressure. The results (Fig. 2) indicated that useful quantities of steam could be extracted from vertical channels at reasonably low steam volume fractions and pointed the way toward laboratory tests at higher pressures.

The 600 lb/sq.in. abs. multi-channel boiler was built to get design information on power *vs.* steam volume fraction for EBWR. The 600 lb/sq.in. abs. single-channel boiler was built to get information on slip ratios and boiling pressure drop. The results from these systems are shown in figures throughout the article.

## GLOSSARY OF SYMBOLS USED IN THIS ARTICLE

**Primary Letter Symbols**

| | |
|---|---|
| $A$ | total flow area, sq.ft. |
| $C_p$ | specific heat at constant pressure, B.t.u./lb/°F. |
| $d$ | differential operator. |
| $D$ | equivalent hydraulic diameter, defined as 4(flow area/wetted perimeter). |
| $f$ | fanning friction factor. |
| $g_c$ | conversion factor, lb mass ft/lb force sec². |
| $G$ | mass velocity, lb/hr/sq.ft. |
| $h$ | enthalpy, B.t.u./lb. |
| $H$ | miscellaneous velocity head losses due to restrictions in downcomer, turning losses, etc., based on the velocity at the inception of boiling. |
| $H_f$ | frictional head loss, ft. |
| $kW/l$ | power density, kilowatts per litre of coolant. |
| $L$ | length, ft. |
| $N$ | exponent on area ratio. |
| $P$ | pressure, lb/sq.ft. |
| $q''$ | heat transfer rate per unit area, B.t.u./hr/sq.ft. |
| $Q$ | heat transfer rate, B.t.u./hr. |
| $r$ | acceleration pressure drop multiplier, cu.ft/lb. |
| $R$ | local two-phase friction factor multiplier. |
| $\bar{R}$ | average two-phase friction factor multiplier. |
| $T$ | temperature, °F. |
| $v$ | specific volume. |
| $V$ | velocity, ft/sec. |
| $W$ | weight rate of flow, lb/hr. |
| $X$ | quality, ratio of vapour flow rate to total mixture flow rate. |
| $x$ | $\frac{\text{lb vapour/hr}}{\text{lb mix/hr}}$ |

**Primary Greek Symbols**

| | |
|---|---|
| $\alpha$ | volume fraction, ratio of vapour phase flow area to total flow area at a point. |
| $\Delta$ | difference, finite. |
| $\rho$ | density, lb/cu.ft. |
| $\bar{\rho}$ | average density, lb/cu.ft. |
| $\Phi_g^2$ | Martinelli parameter based on gaseous phase. |
| $\varphi$ | function. |
| $\psi$ | product of slip ratio and density ratio. |

**Subscripts**

| | |
|---|---|
| B | boiling. |
| C | core. |
| D | downcomer. |
| e | refers to exit of the core. |
| f | saturated liquid. |
| fg | refers to change by evaporation. |
| g | saturated vapour, gaseous phase. |
| i | refers to core inlet. |
| l | liquid phase. |
| $l_o$ | refers to total flow rate flowing as saturated liquid. |
| m | make-up. |
| NB | non-boiling. |
| o | point in core where mixture reaches saturated conditions. |
| R | riser. |
| T | total. |
| TP | two-phase. |
| w | wall. |

Since EBWR has been placed into operation, the experimental programme has been directed toward obtaining more refined basic data on relative velocity of steam water mixtures, two-phase friction factors, and hydrodynamic stability during boiling. This information is required for the design of large scale central station boiling reactors. Following is a description of more recent data.

*Relative velocity of steam water mixtures:* From a mass balance at a plane perpendicular to the flow of a steam water mixture, it may be shown that:

$$\frac{V_g}{V_f}=\left(\frac{x}{1-x}\right)\left(\frac{1-\alpha}{\alpha}\right)\frac{\rho_f}{\rho_g} \qquad \text{(i)}$$

The importance of having information on $V_g/V_f$ lies in the fact that power generation for a given value of $\alpha$ is proportional to $x$. The above equation shows that $x$ increases as $V_g/V_f$ increases. $V_g/V_f$ must therefore be known in order to evaluate power generation in a boiling reactor.

There are currently many ways of calculating $V_g/V_f$ and many ways of interpreting experimental information on this subject. Additional equations relating the variables of interest are:

$$Q_T=\rho_f A V_0[C_p(T_f-T_i)+xh_{fg}] \qquad \text{(ii)}$$

$$V_g-V_f=V_0\left[\frac{x}{\alpha}\frac{\rho_f}{\rho_g}-\frac{1-x}{1-\alpha}\right] \qquad \text{(iii)}$$

These equations show that $V_g-V_f$, $V_0$, $x$, $Q_T$, $V_g-V_f$, etc., are all interrelated. The correct interpretation of data and the selection of the proper variables are presently matters of personal preference. Figs. 3,

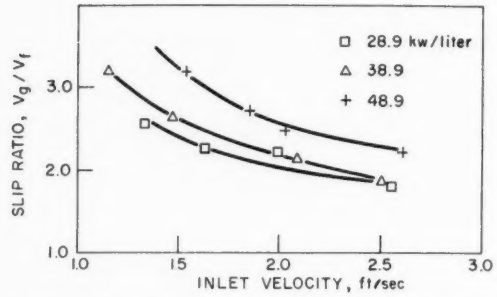



**Fig. 3—Slip ratio *v.* inlet velocity for a 1 in. × 2 in. × 60 in. channel, at 600 lb/sq.in.**

4 and 5 show several ways of presenting the information. Fig. 3 shows slip ratio as a function of inlet velocity. There is a separation with power density. Fig. 4 shows slip ratios as a function of quality with pressure as a parameter.

## For Convenience

Fig. 5 represents the authors' opinion of best available estimates of $V_g/V_t$ shown as functions of mass flow rate and pressure. This form of showing the information was selected since it is very convenient for calculating reactor performance.

*Air-water system studies:* In an analysis of a natural circulation system it is necessary to evaluate the effect of a sudden change of flow area (such as an expansion or a contraction) on the two-phase fluid density. Utilizing information previously available it was difficult to predict these changes. Therefore, an experimental programme was undertaken to provide adequate information on the effect of flow area changes on the two-phase fluid density and to explore further the factors which affect the relative velocity of the two phases.

The experimental apparatus used consisted of a water and air injection system, a mixing section, the test sections and an air water separator. The metered air and water streams were injected into the mixer where the two fluids were mixed. The two-phase mixture then flowed through the test sections and into the overhead separator where the air was allowed to escape and the water was diverted back to the make-up tank. The rectangular test sections, of 2 in. width and 4 ft length with spacings of $\frac{1}{4}$ in., $\frac{1}{2}$ in., $\frac{1}{8}$ in., $\frac{3}{4}$ in. and 1 in., were constructed of Lucite to allow visual and photographic studies of the various flow patterns at the transition zones.

The variables studied were:—(*a*) flow area changes, minimum 1.25:1 and maximum of 8:1; (*b*) air volume fraction, $\alpha$, 0.2 to 0.8; (*c*) mass velocity, $G$, 250,000 to 2,000,000 lb/hr/sq.ft; and (*d*) water velocity $V_l$, 1 ft/sec to 10 ft/sec.

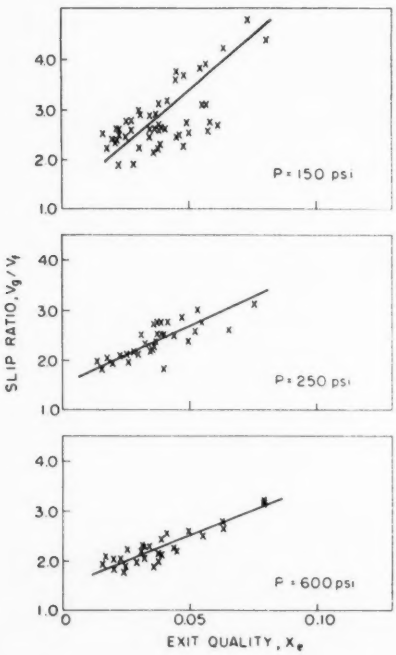



**Fig. 4—Slip ratio *v.* exit quality for various pressures**

A series of runs with varying air volume fractions and different flow area combinations was made and the change in the air volume fraction was measured.

Air volume fractions were determined by measuring the attenuation of monoenergetic gamma rays from thulium-170. The method and errors associated with the method have been described by Hooker and Popper[1]. The measurements were made at the exit of the lower section immediately preceding the flow area change and in the upper section.

## Why the Change

The data showed that the air volume fraction, and hence the density of the air water mixture, changed due to an expansion or contraction of flow area. The magnitude of the change at atmospheric pressure can be predicted by the following semi-theoretical equation:—

$$\alpha_2 = \left[ \frac{\left(\frac{1}{\alpha_1} - 1\right)}{\left(\frac{A_1}{A_2}\right)^{0.2}} + 1 \right]^{-1} \qquad \text{(iv)}$$

A comparison between the predicted and the actual change in the air volume fraction for a series of runs is shown in Fig. 6. The change in the air volume fraction with change in flow area is due to the variation of the slip ratio with the fluid velocity. Typical data showing this variation are shown in Fig. 7. It can also be seen that the relative velocity of the air and water phase is a function of the mixture quality $x$.

Photographic studies showed that the length of the transition zone

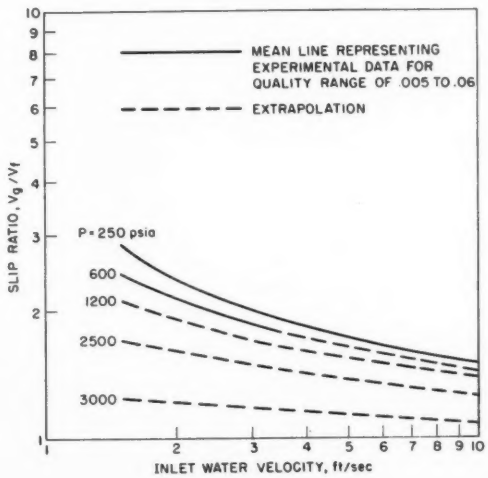
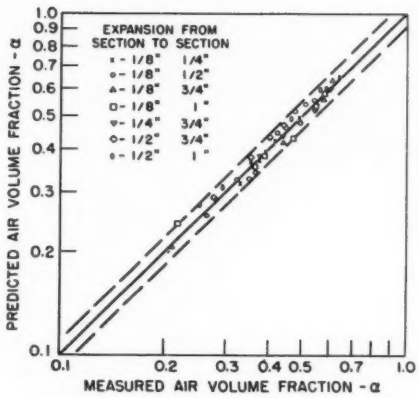



**Fig. 5—Estimated variation of slip ratios with velocity and pressure**


EXPANSION FROM SECTION TO SECTION
x - 1/8" 1/4"
o - 1/8" 1/2"
Δ - 1/8" 3/4"
□ - 1/8" 1"
▽ - 1/4" 3/4"
◇ - 1/2" 3/4"
• - 1/2" 1"
PREDICTED AIR VOLUME FRACTION - α
MEASURED AIR VOLUME FRACTION - α

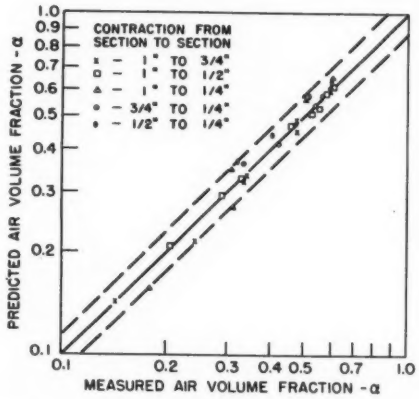

CONTRACTION FROM SECTION TO SECTION
x - 1" TO 3/4"
□ - 1" TO 1/2"
Δ - 1" TO 1/4"
• - 3/4" TO 1/4"
• - 1/2" TO 1/4"
PREDICTED AIR VOLUME FRACTION - α
MEASURED AIR VOLUME FRACTION - α

**Fig. 6—Comparison of the predicted and measured air volume fraction for a series of contractions and expansions**

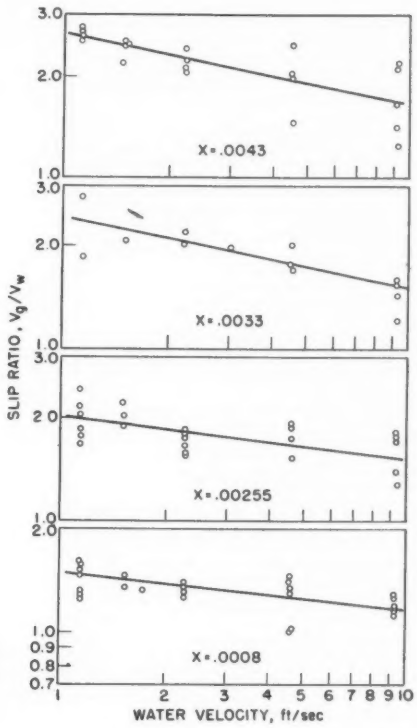



**Fig. 7—Variation of the slip ratio ($V_g/V_f$) with water velocity and quality and atmospheric pressure**

following an expansion or contraction of flow area is a function of the mixture quality, mass velocity and the area ratio.

The distribution of the air phase in the water phase was also studied by traversing the two-phase fluid with a $^1/_{32}$ in. wide gamma beam (from the thulium source). It was found that the distribution of the air phase in the water phase was parabolic in nature but the ratio of $\alpha_{max}/\alpha_{average}$ which characterized the distribution varied at random.

*Two-phase frictional pressure drop:* The two-phase frictional pressure drop in a boiling channel is commonly expressed as:

$$\triangle P_{TP} = \frac{f_f G^2}{2g_c \rho_f D} \int_0^{L_B} R dL = R \frac{f_f G^2 L_B}{2g_c \rho_f D} \quad \text{(v)}$$

where $$R = \frac{(dP/dL)_{TP}}{(dP/dL)_{10}} \quad \text{(vi)}$$

The difficulty in evaluating the above equation lies in obtaining the correct two-phase friction factor multiplier $R$. No general correlation will be recommended in this article; however, it is anticipated that the following brief discussion on some of the latest work in the field will provide some insight into the advantages and shortcomings of the many correlations available.

There appears to be a relation between two-phase frictional pressure drop and the type of two-phase flow pattern involved, *i.e.*, bubble flow, slug flow, annular flow, etc. The ability to predict this frictional pressure drop is complicated by the inability to adequately predict these flow regimes. The first significant attempt was made by Martinelli, *et al*[2], who presented a correlation for adiabatic, two-phase, two-component flow. Their semi-empirical correlation:

$$\Phi_g^2 = \frac{(dP/dL)_{TP}}{(dP/dL)_g} = \phi\left[\frac{(dP/dL)_f}{(dP/dL)_g}\right] \quad \text{(vii)}$$

was derived for four types of flow depending on whether each phase was flowing viscously or turbulently. The flow mechanisms described in this manner have no apparent relation to the flow regimes mentioned previously.

The most significant and widely accepted work to date is that of Martinelli and Nelson[3]. They modified Martinelli's previous model to apply to steam-water mixtures and developed curves of the local pressure $(dP/dL)_{TP}$ gradient as a function of $(dP/dL)_{10}$ quality and pressure for the most common flow mechanism, that in which both phases are flowing turbulently. They also presented a curve of the mean pressure gradient in a uniformly heated boiling channel. The experimental data used in these papers came from low pressure, adiabatic, two-component flow in horizontal pipes and the pressure parameters of the curves they present are largely interpolated from this low pressure data and the conditions at the critical point.

*(To be continued)*

**References**

[1]HOOKER, H. H., and POPPER, G. F., "A Gamma Ray Attenuation Method for Void Fraction Determination in Steam-Water Mixtures." ANL-5766, 1958.

[2]MARTINELLI, R. C., BOELTER, L. M. K., TAYLOR, T. H. M., THOMSEN, E. G., and MORRIN, E. H., "Isothermal Pressure Drop for Two-Component Flow in a Horizontal Pipe." *Trans.Ame.Soc.Mech.Engr.* 66:139 (1944).

[3]MARTINELLI, R. C., and NELSON, B. D. "Prediction of Pressure Drop During Forced Circulation Boiling of Water." *Trans. Am. Soc. Mech. Engr.* 70:695-702 (1948).

# TABULAR DEVICE FOR DESK CALCULATIONS

THE "Unical" decimal desk calculator, manufactured in Switzerland, is being introduced for the first time in this country. It has been in use on the Continent for a number of years and is a new approach to calculations. Basically it consists of 99 tables on which a great many variations of the numbers from 1 to 9999 are precalculated.

Anyone who has a technical background can learn and fully understand this system in a very short time. but even without technical knowledge it can be learned by following a few basic rules. It can be used for most technical calculations and for sums of money if they are decimalized or in decimal currency.

The ideal application is for calculations involving initially up to 4 digits as a basic sum, but if no other machinery is available it is, in principle, quite unlimited in multiplication but in division the divisor cannot exceed 4 digits. A multiplication of up to 4 digits by up to 8 digits can be carried out speedily, and an unlimited dividend can be divided by a divisor of up to 4 digits easily and quickly.

An interesting part of the calculator is the fraction portion at the bottom of each table.

### Complete Accuracy

In multiplication one obtains complete accuracy without limitation, if necessary with the aid of the tables of differences in the centre position between the two vertical columns of multipliers, which fill the complete range (*e.g.*, 10.41, 10.42, 10.43, 10.44 and 10.46, 10.47, etc.). In division one obtains any desired number of decimal places by subtraction.

As each number from 1 to 9995 (+4) is developed individually the precalculated results can be read in comparative calculations such as different percentages, changing quantities, values for different months, or statistical breakdown using the top multiplicand as the constant.

By referring to the portions of Table 10 reproduced here, the following simple examples can be followed:

*Example digit:* 10.45

$10.45 \times 21 = 219.45$

$1045 \times 21 = 21945$

21 per cent. of 1045 = 219.45

21 per cent. of 1.045 = 0.21945

2.1 per cent. of 1.045 = 0.021945

$10.45^2 = 10.45 \times 10.45$

add results of $10.. \times 1045$

and $45 \times 1045$

$= 10450..$

$47025$

$109.2025$

$\frac{10.45}{6} = 1.7417$ (see bottom portion—fractions)

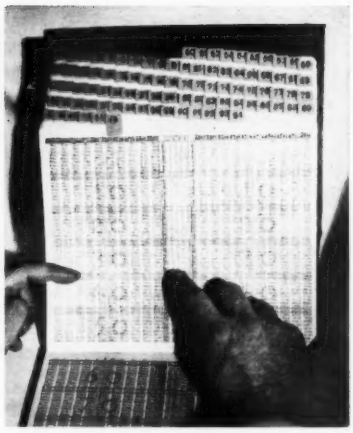
1045 per hour = 17.417 per minute ($^1/_{60}$)

1045 per year = 87.08 per month ($^1/_{12}$)

$10.45 \times .625 = 6.5313$ ($^5/_8$)

10.45 less $33^1/_3$ per cent. = 6.9667 ($^2/_3$)

$\frac{10.45}{16} = 0.6531$ ($^1/_{16}$)



$3\frac{3}{4}$ per cent. of 1045 = 39.188 ($^3/_8$)

yearly total = 1045

4 weeks = 80.38 ($^1/_{13}$)

1 week = 20.10 ($^1/_{52}$)

10.50 (or 10*s.* 6*d.*)

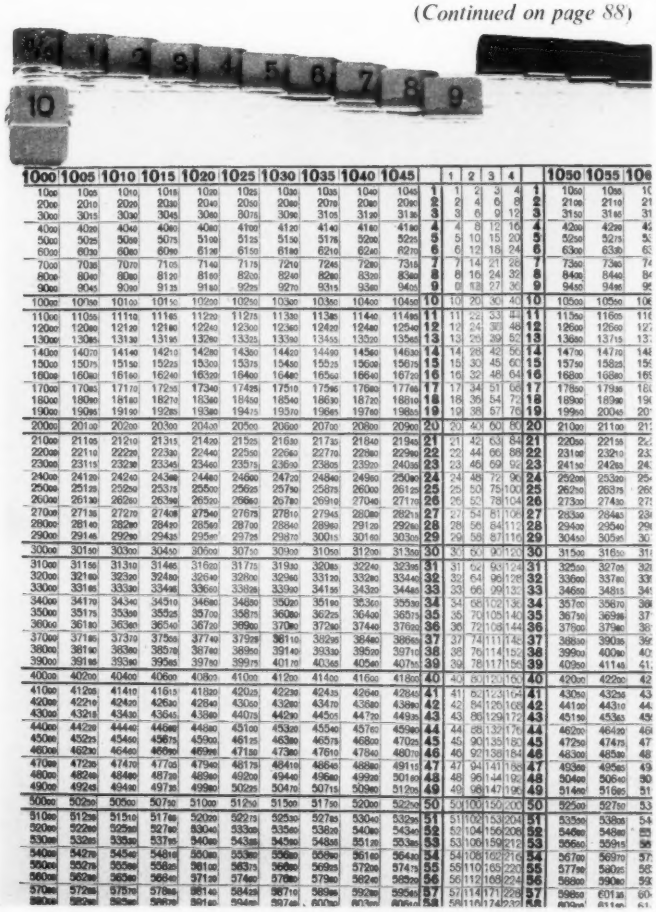
10.50

0.735 (less 7 per cent.)

9.765 nett (read nett result immediately against 93)

(approximately 9*s.* 9¼*d.*)

(*Continued on page 88*)



| 1000 | 1005 | 1010 | 1015 | 1020 | 1025 | 1030 | 1035 | 1040 | 1045 | | 1 | 2 | 3 | 4 | | 1050 | 1055 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.00 | 10.05 | 10.10 | 10.15 | 10.20 | 10.25 | 10.30 | 10.35 | 10.40 | 10.45 | 1 | 1 | 2 | 3 | 4 | 1 | 10.50 | 10.55 | 1 |
| 20.00 | 20.10 | 20.20 | 20.30 | 20.40 | 20.50 | 20.60 | 20.70 | 20.80 | 20.90 | 2 | 2 | 4 | 6 | 8 | 2 | 21.00 | 21.10 | 2 |
| 30.00 | 30.15 | 30.30 | 30.45 | 30.60 | 30.75 | 30.90 | 31.05 | 31.20 | 31.35 | 3 | 3 | 6 | 9 | 12 | 3 | 31.50 | 31.65 | 3 |
| 40.00 | 40.20 | 40.40 | 40.60 | 40.80 | 41.00 | 41.20 | 41.40 | 41.60 | 41.80 | 4 | 4 | 8 | 12 | 16 | 4 | 42.00 | 42.20 | 4 |
| 50.00 | 50.25 | 50.50 | 50.75 | 51.00 | 51.25 | 51.50 | 51.75 | 52.00 | 52.25 | 5 | 5 | 10 | 15 | 20 | 5 | 52.50 | 52.75 | 5 |
| 60.00 | 60.30 | 60.60 | 60.90 | 61.20 | 61.50 | 61.80 | 62.10 | 62.40 | 62.70 | 6 | 6 | 12 | 18 | 24 | 6 | 63.00 | 63.30 | 6 |
| 70.00 | 70.35 | 70.70 | 71.05 | 71.40 | 71.75 | 72.10 | 72.45 | 72.80 | 73.15 | 7 | 7 | 14 | 21 | 28 | 7 | 73.50 | 73.85 | 7 |
| 80.00 | 80.40 | 80.80 | 81.20 | 81.60 | 82.00 | 82.40 | 82.80 | 83.20 | 83.60 | 8 | 8 | 16 | 24 | 32 | 8 | 84.00 | 84.40 | 8 |
| 90.00 | 90.45 | 90.90 | 91.35 | 91.80 | 92.25 | 92.70 | 93.15 | 93.60 | 94.05 | 9 | 9 | 18 | 27 | 36 | 9 | 94.50 | 94.95 | 9 |
| 100.00 | 100.50 | 101.00 | 101.50 | 102.00 | 102.50 | 103.00 | 103.50 | 104.00 | 104.50 | 10 | 10 | 20 | 30 | 40 | 10 | 105.00 | 105.50 | 10 |
| 110.00 | 110.55 | 111.10 | 111.65 | 112.20 | 112.75 | 113.30 | 113.85 | 114.40 | 114.95 | 11 | 11 | 22 | 33 | 44 | 11 | 115.50 | 116.05 | 11 |
| 120.00 | 120.60 | 121.20 | 121.80 | 122.40 | 123.00 | 123.60 | 124.20 | 124.80 | 125.40 | 12 | 12 | 24 | 36 | 48 | 12 | 126.00 | 126.60 | 12 |
| 130.00 | 130.65 | 131.30 | 131.95 | 132.60 | 133.25 | 133.90 | 134.55 | 135.20 | 135.85 | 13 | 13 | 26 | 39 | 52 | 13 | 136.50 | 137.15 | 13 |
| 140.00 | 140.70 | 141.40 | 142.10 | 142.80 | 143.50 | 144.20 | 144.90 | 145.60 | 146.30 | 14 | 14 | 28 | 42 | 56 | 14 | 147.00 | 147.70 | 14 |
| 150.00 | 150.75 | 151.50 | 152.25 | 153.00 | 153.75 | 154.50 | 155.25 | 156.00 | 156.75 | 15 | 15 | 30 | 45 | 60 | 15 | 157.50 | 158.25 | 15 |
| 160.00 | 160.80 | 161.60 | 162.40 | 163.20 | 164.00 | 164.80 | 165.60 | 166.40 | 167.20 | 16 | 16 | 32 | 48 | 64 | 16 | 168.00 | 168.80 | 16 |
| 170.00 | 170.85 | 171.70 | 172.55 | 173.40 | 174.25 | 175.10 | 175.95 | 176.80 | 177.65 | 17 | 17 | 34 | 51 | 68 | 17 | 178.50 | 179.35 | 18 |
| 180.00 | 180.90 | 181.80 | 182.70 | 183.60 | 184.50 | 185.40 | 186.30 | 187.20 | 188.10 | 18 | 18 | 36 | 54 | 72 | 18 | 189.00 | 189.90 | 19 |
| 190.00 | 190.95 | 191.90 | 192.85 | 193.80 | 194.75 | 195.70 | 196.65 | 197.60 | 198.55 | 19 | 19 | 38 | 57 | 76 | 19 | 199.50 | 200.45 | 20 |
| 200.00 | 201.00 | 202.00 | 203.00 | 204.00 | 205.00 | 206.00 | 207.00 | 208.00 | 209.00 | 20 | 20 | 40 | 60 | 80 | 20 | 210.00 | 211.00 | 21 |
| 210.00 | 211.05 | 212.10 | 213.15 | 214.20 | 215.25 | 216.30 | 217.35 | 218.40 | 219.45 | 21 | 21 | 42 | 63 | 84 | 21 | 220.50 | 221.55 | 22 |
| 220.00 | 221.10 | 222.20 | 223.30 | 224.40 | 225.50 | 226.60 | 227.70 | 228.80 | 229.90 | 22 | 22 | 44 | 66 | 88 | 22 | 231.00 | 232.10 | 23 |
| 230.00 | 231.15 | 232.30 | 233.45 | 234.60 | 235.75 | 236.90 | 238.05 | 239.20 | 240.35 | 23 | 23 | 46 | 69 | 92 | 23 | 241.50 | 242.65 | 24 |
| 240.00 | 241.20 | 242.40 | 243.60 | 244.80 | 246.00 | 247.20 | 248.40 | 249.60 | 250.80 | 24 | 24 | 48 | 72 | 96 | 24 | 252.00 | 253.20 | 25 |
| 250.00 | 251.25 | 252.50 | 253.75 | 255.00 | 256.25 | 257.50 | 258.75 | 260.00 | 261.25 | 25 | 25 | 50 | 75 | 100 | 25 | 262.50 | 263.75 | 26 |
| 260.00 | 261.30 | 262.60 | 263.90 | 265.20 | 266.50 | 267.80 | 269.10 | 270.40 | 271.70 | 26 | 26 | 52 | 78 | 104 | 26 | 273.00 | 274.30 | 27 |
| 270.00 | 271.35 | 272.70 | 274.05 | 275.40 | 276.75 | 278.10 | 279.45 | 280.80 | 282.15 | 27 | 27 | 54 | 81 | 108 | 27 | 283.50 | 284.85 | 28 |
| 280.00 | 281.40 | 282.80 | 284.20 | 285.60 | 287.00 | 288.40 | 289.80 | 291.20 | 292.60 | 28 | 28 | 56 | 84 | 112 | 28 | 294.00 | 295.40 | 29 |
| 290.00 | 291.45 | 292.90 | 294.35 | 295.80 | 297.25 | 298.70 | 300.15 | 301.60 | 303.05 | 29 | 29 | 58 | 87 | 116 | 29 | 304.50 | 305.95 | 30 |
| 300.00 | 301.50 | 303.00 | 304.50 | 306.00 | 307.50 | 309.00 | 310.50 | 312.00 | 313.50 | 30 | 30 | 60 | 90 | 120 | 30 | 315.00 | 316.50 | 31 |
| 310.00 | 311.55 | 313.10 | 314.65 | 316.20 | 317.75 | 319.30 | 320.85 | 322.40 | 323.95 | 31 | 31 | 62 | 93 | 124 | 31 | 325.50 | 327.05 | 32 |
| 320.00 | 321.60 | 323.20 | 324.80 | 326.40 | 328.00 | 329.60 | 331.20 | 332.80 | 334.40 | 32 | 32 | 64 | 96 | 128 | 32 | 336.00 | 337.60 | 33 |
| 330.00 | 331.65 | 333.30 | 334.95 | 336.60 | 338.25 | 339.90 | 341.55 | 343.20 | 344.85 | 33 | 33 | 66 | 99 | 132 | 33 | 346.50 | 348.15 | 34 |
| 340.00 | 341.70 | 343.40 | 345.10 | 346.80 | 348.50 | 350.20 | 351.90 | 353.60 | 355.30 | 34 | 34 | 68 | 102 | 136 | 34 | 357.00 | 358.70 | 36 |
| 350.00 | 351.75 | 353.50 | 355.25 | 357.00 | 358.75 | 360.50 | 362.25 | 364.00 | 365.75 | 35 | 35 | 70 | 105 | 140 | 35 | 367.50 | 369.25 | 37 |
| 360.00 | 361.80 | 363.60 | 365.40 | 367.20 | 369.00 | 370.80 | 372.60 | 374.40 | 376.20 | 36 | 36 | 72 | 108 | 144 | 36 | 378.00 | 379.80 | 38 |
| 370.00 | 371.85 | 373.70 | 375.55 | 377.40 | 379.25 | 381.10 | 382.95 | 384.80 | 386.65 | 37 | 37 | 74 | 111 | 148 | 37 | 388.50 | 390.35 | 39 |
| 380.00 | 381.90 | 383.80 | 385.70 | 387.60 | 389.50 | 391.40 | 393.30 | 395.20 | 397.10 | 38 | 38 | 76 | 114 | 152 | 38 | 399.00 | 400.90 | 40 |
| 390.00 | 391.95 | 393.90 | 395.85 | 397.80 | 399.75 | 401.70 | 403.65 | 405.60 | 407.55 | 39 | 39 | 78 | 117 | 156 | 39 | 409.50 | 411.45 | 41 |
| 400.00 | 402.00 | 404.00 | 406.00 | 408.00 | 410.00 | 412.00 | 414.00 | 416.00 | 418.00 | 40 | 40 | 80 | 120 | 160 | 40 | 420.00 | 422.00 | 42 |
| 410.00 | 412.05 | 414.10 | 416.15 | 418.20 | 420.25 | 422.30 | 424.35 | 426.40 | 428.45 | 41 | 41 | 82 | 123 | 164 | 41 | 430.50 | 432.55 | 43 |
| 420.00 | 422.10 | 424.20 | 426.30 | 428.40 | 430.50 | 432.60 | 434.70 | 436.80 | 438.90 | 42 | 42 | 84 | 126 | 168 | 42 | 441.00 | 443.10 | 44 |
| 430.00 | 432.15 | 434.30 | 436.45 | 438.60 | 440.75 | 442.90 | 445.05 | 447.20 | 449.35 | 43 | 43 | 86 | 129 | 172 | 43 | 451.50 | 453.65 | 45 |
| 440.00 | 442.20 | 444.40 | 446.60 | 448.80 | 451.00 | 453.20 | 455.40 | 457.60 | 459.80 | 44 | 44 | 88 | 132 | 176 | 44 | 462.00 | 464.20 | 46 |
| 450.00 | 452.25 | 454.50 | 456.75 | 459.00 | 461.25 | 463.50 | 465.75 | 468.00 | 470.25 | 45 | 45 | 90 | 135 | 180 | 45 | 472.50 | 474.75 | 47 |
| 460.00 | 462.30 | 464.60 | 466.90 | 469.20 | 471.50 | 473.80 | 476.10 | 478.40 | 480.70 | 46 | 46 | 92 | 138 | 184 | 46 | 483.00 | 485.30 | 48 |
| 470.00 | 472.35 | 474.70 | 477.05 | 479.40 | 481.75 | 484.10 | 486.45 | 488.80 | 491.15 | 47 | 47 | 94 | 141 | 188 | 47 | 493.50 | 495.85 | 49 |
| 480.00 | 482.40 | 484.80 | 487.20 | 489.60 | 492.00 | 494.40 | 496.80 | 499.20 | 501.60 | 48 | 48 | 96 | 144 | 192 | 48 | 504.00 | 506.40 | 50 |
| 490.00 | 492.45 | 494.90 | 497.35 | 499.80 | 502.25 | 504.70 | 507.15 | 509.60 | 512.05 | 49 | 49 | 98 | 147 | 196 | 49 | 514.50 | 516.95 | 51 |
| 500.00 | 502.50 | 505.00 | 507.50 | 510.00 | 512.50 | 515.00 | 517.50 | 520.00 | 522.50 | 50 | 50 | 100 | 150 | 200 | 50 | 525.00 | 527.50 | 53 |
| 510.00 | 512.55 | 515.10 | 517.65 | 520.20 | 522.75 | 525.30 | 527.85 | 530.40 | 532.95 | 51 | 51 | 102 | 153 | 204 | 51 | 535.50 | 538.05 | 54 |
| 520.00 | 522.60 | 525.20 | 527.80 | 530.40 | 533.00 | 535.60 | 538.20 | 540.80 | 543.40 | 52 | 52 | 104 | 156 | 208 | 52 | 546.00 | 548.60 | 55 |
| 530.00 | 532.65 | 535.30 | 537.95 | 540.60 | 543.25 | 545.90 | 548.55 | 551.20 | 553.85 | 53 | 53 | 106 | 159 | 212 | 53 | 556.50 | 559.15 | 56 |
| 540.00 | 542.70 | 545.40 | 548.10 | 550.80 | 553.50 | 556.20 | 558.90 | 561.60 | 564.30 | 54 | 54 | 108 | 162 | 216 | 54 | 567.00 | 569.70 | 57 |
| 550.00 | 552.75 | 555.50 | 558.25 | 561.00 | 563.75 | 566.50 | 569.25 | 572.00 | 574.75 | 55 | 55 | 110 | 165 | 220 | 55 | 577.50 | 580.25 | 58 |
| 560.00 | 562.80 | 565.60 | 568.40 | 571.20 | 574.00 | 576.80 | 579.60 | 582.40 | 585.20 | 56 | 56 | 112 | 168 | 224 | 56 | 588.00 | 590.80 | 59 |
| 570.00 | 572.85 | 575.70 | 578.55 | 581.40 | 584.25 | 587.10 | 589.95 | 592.80 | 595.65 | 57 | 57 | 114 | 171 | 228 | 57 | 598.50 | 601.35 | 60 |
| 580.00 | 582.90 | 585.80 | 588.70 | 591.60 | 594.50 | 597.40 | 600.30 | 603.20 | 606.10 | 58 | 58 | 116 | 174 | 232 | 58 | 609.00 | 611.90 | 61 |

# PEOPLE... in the NUCLEAR NEWS

"To ensure the best possible labour relations" during the building of Trawsfynydd nuclear power station, Atomic Power Constructions Ltd., the contractors, have engaged **MR. ALFRED ROBENS,** the Labour politician, as labour adviser. Commenting on his appointment, Mr. Robens, who is the Labour party's "shadow Minister of Labour," says that he regards the decision of the contractors to call in a consultant at the start of a project of the Trawsfynydd size was a great challenge. "The industrial and economic gains might be tremendous," he is reported to have said, "if we could get this job done on time, with safety on the site, and with efficiency, it would be a tribute to British labour and management and would help Britain's export trade to the benefit of all." Work on the site started in July last and is expected to take about five years to complete. Working force is now about 500 but will rise to 5,000 before the project is finished.

**MR. G. P. DAVIDSON** has been appointed managing director of Head Wrightson Processes Ltd., the subsidiary of Head Wrightson & Co., Ltd., responsible for all the group's nuclear research and power interests. Mr. Davidson, who joined Head Wrightson & Co., Ltd., in 1956 as general manager of their nuclear power division,

Mr. G. P. Davidson

was educated in Germany and Sweden and qualified as a mechanical engineer in Stockholm. He later spent a number of years on marine work, following which his experience has been mainly gained from oil refinery and petro-chemical work with Foster Wheeler, Shell Refining and Marketing Co., and the Distillers Co., Ltd.

New principal of the Indian Government's Naval Engineering College at Lonavala, Bombay State, is **MR. SANTHANAN KASTHURI,** AMIMechE, AMIE(Ind), AMINA, formerly vice-principal of the Nautical and Engineering College, Bombay. Holder of a U.K. Ministry of Transport Extra First Class Engineer's Certificate, Mr. Kasthuri was for eight years a sea-going engineer with the Scindia Steam Navigation Co., Ltd. In 1948 he was appointed a lecturer in marine engineering in the Indian Ministry of Transport's Shipping Department. Five years later he was promoted to deputy director of marine engineering training and later became vice-principal of the Naval and Engineering College, Bombay. Mr. Kasthuri is one of the 500 founder members of the Institution of Nuclear Engineers.

**MR. JOHN HARRISON** has been appointed managing director of Atlas Copco (Great Britain) Ltd., of Hemel Hempstead, Hertfordshire, in place of **MR. J. C. GREIG,** who has resigned. Mr. Harrison has been with the Atlas Copco international group of companies for six

Mr. J. Harrison

years. He was born in 1916 at Ashington, Northumberland, and apprenticed to the Ashington Coal Co. in 1931. He stayed with this company until 1942. In 1943 he was appointed assistant manager at Hilton Main Colliery, Staffordshire. In the following year he became manager of the Princess Royal and Norchard Collieries in Gloucestershire. After nationalization of the coal industry Mr. Harrison was appointed an area production manager of the National Coal Board, and served in this capacity for five years. He joined Atlas Copco in 1953 and was shortly given the task of setting up the Cyprus company which he ran as managing director from 1953-1957. In 1957 he was transferred to the firm's New Zealand company as managing director, returning to Britain—in the capacity of deputy managing director of Atlas Copco (Great Britain) Ltd.—in June, 1959.

The Director General of the International Atomic Energy Agency, Mr. Sterling Cole, has appointed **PROFESSOR PAULO RIBEIRO DE ARRUDA,** of Brazil, as director of the Agency's Division of Exchange and Training in the Department of Training and Technical Information. Professor Arruda was professor of applied electricity and lecturer on applied electronics at the Polytechnical School of the University of Sao Paulo and also director of research at the Electronic Microscopy Department of the same university. In his new post he succeeds Professor Joachim da Costa-Ribeiro, also of Brazil, whose contract has expired. Professor Arruda has published a number of scientific papers on radio-electricity and electronics and submitted a paper on the training of personnel for atomic energy in under-developed countries to the second Geneva Atoms-for-Peace Conference in 1958.

**DR. KARL G. KESSLER** has been appointed chief of the spectroscopy section of the U.S. National Bureau of Standards. In this capacity he will direct work in interferometry, analysis of spectra, and the study of hyperfine structure and isotope shift in spectra. He will continue to head the Bureau project to develop a new wavelength standard of length utilizing atomic beams as a light source. Born in Hamburg, Germany, in 1919, Dr. Kessler attended the University of Michigan, and received his Bachelor degree in physics in 1941, his Master of Science degree in 1942, and his doctorate in 1947. From 1942 to 1948 he was also a research physicist and instructor with the university.

As a result of reorganization, the board of the Chemical and Insulating Co., Ltd., has been reconstituted as follows: **MR. D. J. GRANT,** chairman, **MR. F. R. GIBSON,** managing director, **MR. G. BANKS, MR. K. C. PLUMBE** and **MR. F. SAWDON.**

**SIR OWEN WANSBROUGH-JONES,** KBE, CB, formerly chief scientist of the Ministry of Supply, has been appointed a director of The British Oxygen Co., Ltd.

**MR. KENNETH BAIRD** has been appointed personnel manager of F. Perkins, Ltd., of Peterborough. Mr. Baird, who is 37, has been head of the Industrial Welfare Society's education and training department since 1955.

**MR. T. B. ELLIS** has been appointed secretary of The General Electric Co., Ltd. He takes over from **MR. T. B. O. KERR,** who was recently appointed director for finance and administration. Aged 41, Mr. Ellis joined the GEC in 1949 as a trainee. On completion of his training he went on to Mr. Kerr's staff as his personal assistant. In 1956 he was appointed assistant secretary of the company. Before joining GEC Mr. Ellis was a regular officer serving with the King's Shropshire Light Infantry.

**MR. R. H. VIVIAN,** BSc, AMIEE, has joined Wireless Telephone Co., Ltd., as chief engineer. Mr. Vivian has had extremely wide experience of transistor application and has designed several basic transistor circuits which are widely used in radio receivers. For many years he was development engineer in charge of transistor investigations and applications with A. C. Cossor, Ltd.

# Book Reviews

**Radiation Hygiene Handbook.** Editor-in-Chief, Hanson Blatz. Published by McGraw-Hill Publishing Co., Ltd. Size 9 in. × 6 in. × 650 pp. Price £10 13s. 0d.

As a new scientific subject grows a stage is reached when a reference handbook becomes essential for practitioners requiring easy access to a wealth of data, scattered widely in the literature. This stage has been reached for radiation health physicists, and the volume under review attempts to cater for this need. In the present context the use of the word " hygiene " in the title may appear somewhat strange to English ears, but the scope covered is far wider. It is claimed that this volume constitutes a practical reference covering industrial medical and research uses of radiation and atomic energy. As such it is divided into 23 main sections, including such subjects as four exposure standards and radiation protection regulations; interaction of radiation with matter; laboratory design; industrial research and medical applications; radiation hygiene chemistry; surface contamination and decontamination; physiological effects; liquid and solid waste disposal; control of air pollution, and finally, personnel control. With such a wide range of topics, it is not surprising that some of the information provided tends to be somewhat scant in places, in spite of the considerable size of the volume. Exposure standards and regulations outlined in 72 pages, is devoted almost entirely to American procedures. The section on ionizing radiation is of much wider appeal, and constitutes a useful summary text for students, rather than a computation of formulae. The discussion on natural radioactivity contains a very detailed list of uranium and thorium minerals. The descriptions of particle accelerators, electron sources of X-radiation and nuclear reactors are primarily descriptive, and provide no references to further works. Section 7 dealing with the interaction of radiation with matter is dealt with in 12 pages, and could profitably be amplified. Much of the radiation attenuation data (69 pages) is valuable. Even the *elements* of laboratory design cannot be dealt with in the few pages allotted. Radiation detection and measurement ranks 84 pages. Of these, three are devoted to chemical monitoring, but no mention is made of the use of ferrous sulphate, for example. The sections dealing with Industrial, Research and Medical Applications are concerned with safety precautions. It is surprising, for example, not to find any description of the use of radioactive isotopes for radiographic examination, which is so widespread in many industrial processes. One of the most valuable sections—titled radiation hygiene chemistry—outlines methods for the determination of such health hazards as strontium-90, tritium, uranium, etc. This is followed by a number of other sections of prime interest to the health physicist—equipment decontamination, sampling, disposal of waste. The preceding comments indicate the wide range of aspects covered, and the different approach selected by each author. One can appreciate the difficulty experienced by an editor attempting to impose a more uniform treatment on the work of 38 distinguished contributors. Many of the contributions will be used far more widely than is indicated by the title of the book. The *Radiation Hygiene Handbook* will form an essential part of any laboratories in which radiation is likely to be used; many suggestions will undoubtedly be made for improvements and additions in future editions. To keep the overall size in reasonable limits will entail some restriction in other respects. These may best be achieved by splitting off basic information, of interest to all workers in the field of radiation, from more specialist data.

A. CHARLESBY.
*Royal Military College of Science.*

**Proceedings of the International Conference on Nuclear Physics: Low Energy Nuclear Interactions and Nuclear Structure.** Presented by Mme. P. Gugenberger. Published by Crosby Lockwood & Son Ltd., London. Size 11 in. × 7½ in. × 950pp (180 pp in French). Price 140s. 0d.

The International Union of Pure and Applied Physics has sponsored annual or biennial conferences on Nuclear Physics for some years. These are the proceedings of the latest of these conferences held in Paris in July, 1958. The volume also forms a memorial to the president of the organizing committee, Frederick Joliot, whose tragic death occurred between the conference and the publication of the book. It was the first international conference in Nuclear Physics held in France since the war, and marked the resurgence of French nuclear physics, for which Joliot had worked, and whose foundations he had laid in the inter war years. Delegates to this conference were able to visit the new laboratories built at Orsay for the many Paris schools and the large new accelerator at Saclay. The size of this volume, compared with its forerunners from the Amsterdam and Glasgow conferences, is an indication of the popularity and rapid growth of its subject. The Glasgow conference in 1954 was the last which attempted to cover both the physics of fundamental particles, which uses the very largest accelerators, and the physics of nuclear structures which uses relatively more modest equipment. The Paris conference was restricted to nuclear structure and nuclear reactions. The accelerators used for this type of physics are still modest enough to be operated by individual universities and since this type of data is often of interest to designers of nuclear reactors the subject is also energetically pursued in nuclear energy establishments. This conference account falls into two parts. Because of the large number of papers communicated it is becoming usual to ask an authority on a particular field to read the communications and prepare a report on them and the state of that particular field. The first 300 pages contains these reports and the discussions which took place after them. These reports form a valuable account of the present state of the physics of nuclear structure. The authors vary in their approach to the task but the report by Dr. Levinger on reactors induced by γ-rays is a model of how to cover a large number of communications and produce a clear account of the state of a subject. The discussions finish with the last talk of the conference given by (one might almost add, as usual) Professor Rosenfeld, who was asked to summarize the proceedings. It gives an admirable summary of the present state of low energy nuclear physics. The remaining 600 pages contain the contributed papers from which the reports presented in the first section were culled. These are of doubtful value. They are meant to be reports hot from the laboratory and sometimes are. In the 18 months which intervened between the conference and the publication of this volume, however, many of these reports have been written up and published in more detail in the regular journals and so to some extent their repetition in this book makes them superfluous.

L. L. Green,
*Liverpool University.*

**Sir John Cockcroft, OM,** by Ronald Clark. Published by Phoenix House Ltd., London. Size 7½ in. × 5 in. × 109 pp illustrated. Price 8s. 6d.

This is the second in a series of biographies of famous people still living. Although it is aimed for a youthful readership the informal, narrative style in which the book is written will give it a much wider appeal. Sir John Cockcroft's early days at the Cavendish, his important contributions to the development of RADAR and the winning of the 1939-45 war, and his leadership in the establishment of the British nuclear research and power programmes are all vividly and excitingly recounted. It ends with a brief assessment of Sir John's character and his current work as a sort of Ambassador Extraordinary for nuclear technology. From it all Sir John emerges not only as a brilliant scientist and decisive, practical leader but also as a down-to-earth homely person whom no reader could fail to respect and admire as a fond uncle or next-door neighbour. It is, in fact, the " ordinariness " of Sir John which is emphasized throughout, as though the author is hoping to inspire in his boy and girl readers a yearning and confidence for similar success in the field of scientific endeavour. If indeed the book succeeds in doing this, the author will have accomplished more than just writing an entertaining account of the life of one of our greatest living scientists.

T.R.

# 'NUCLEARIST' writes . . .

BRITAIN certainly takes the cake in the atomic world this month, and I must start by mentioning several of our outstanding achievements. Marching to Aldermaston seems to be a favourite pastime for some, especially on wet Bank Holidays, but now 600 of the public have not only reached its gates, but managed to enter them. They went to celebrate the sixth annual prize-giving of the Apprentice School, and to have a look at the boys at work, under the critical eyes of security police, of course. At present there are 160 apprentices, and the school is inundated with applications from youngsters wanting to jump on the nuclear bandwagon. At present, these lads, who, even more than we, will be citizens of the atomic world, are too young to have any qualms of conscience about the nature of their work at the AWRE. Perhaps by the time they are old enough to have heart-searchings, the establishment will have ceased to exist, and will have reverted to some peacetime activity. If that is so, the techniques learned by these boys will still be extremely useful in keeping Britain well to the fore in nuclear progress.

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Ilford Ltd., have justly secured a place at the head of the world's photographic manufacturers. The U.S. Armed Forces have selected Ilford nuclear emulsion for important new tests. A consignment worth £40,000 was flown to the U.S.A., and will ascend to a height of about 20 miles in balloons of capacity 10m. cu.ft, in a search for more information on the interaction between nuclear particles. Upon the data obtained will depend the U.S. Government's decision whether or not to build huge new accelerators costing $250m. The British film, to be sent into space from the Caribbean, will be processed in Chicago, and sent for examination to scientific institutions all over the world.

* * *

One of the trickiest of natural elements to isolate, protoactinium, a member of the nitrogen group, and the parent of the actinium radioactive disintegration series, is at last available to certain scientists. Almost the world's supply about 100 g, and worth £100,000, is held by the UKAEA, separated from uranium wastes at Windscale. Unfortunately, changes in processing of uranium will mean that no more of this rare element will be obtained. Another rare element made at Windscale is technetium, of which 20 g have been obtained from over 100 tons of fission wastes. It will be interesting to see how far the properties of this element, which cannot be detected in any natural source, conform to those forecast from the position in the periodic table.

* * *

A Labour man to solve labour problems—well, that sounds sensible enough. So, apparently, thought Atomic Power Constructions, Ltd., when they asked Mr. Alfred Robens to become their adviser on labour relations. Mr. Robens, "Minister of Labour" in the Labour Party's shadow government, took up duties with APC on January 1st, and a few days later went to Trawsfynydd, North Wales, where the firm is building a new nuclear power station. With strikes growing in frequency in Britain, it would be strange if there should be no unrest at Trawsfynydd, but Mr. Robens feels that the job will be done on time, and that British prestige is very much at stake. He considers safety as the first objective, and is obviously not prepared to pull his punches either to workers or to management. He goes to a good testing ground for theories which he hopes one day to put to the national good. It sounds as if you're the man for the job, Mr. Robens—good luck to you.

* * *

Professor J. M. Kay, to the Institution of Junior Engineers, made almost the perfect presidential address. He justified Britain's entry into nuclear power generation 10 years before absolutely necessary, and rightly pointed out that the engineer has a part to play in every reactor project right from its conception, not simply during building. He dealt with the British power programme, reactor design problems, and nuclear marine propulsion. In one respect, I felt, he went off the rails. As if trying to reconcile himself to the presidency of an institution of engineers bearing no other adjective than "Junior," he suggests that there is no justification for the term "nuclear engineer." His argument might be said to recommend the closing down of world institutions of civil, mechanical, marine, electrical, and all the other types of engineers, and to take it to a logical conclusion, that microbiologists, palaeobotanists, organic chemists, and rheologists, might all be grouped together as scientists. If anything is needed to shoot down his argument, we need only look at the recent formation of the Institution of Nuclear Engineers, the result of spontaneous demand, and the object of acclaim all over the world.

* * *

American manufacturers and processors of food and chemicals are rushing to comply with the new legislation, passed by Congress in September, 1958, and becoming operative in March, 1960. Under new regulations, it becomes obligatory to test the toxicity of additives before they are used in marketed products. Foodstuffs are likely to contain traces of pesticides, chemicals from the processing plant, defoamers, anti-coagulants, emulsifiers, preservatives, seasonings, flavour modifiers, dyes and pigments. Obviously, analysts are going to be hard pressed to devise completely satisfactory methods for the determination of all of these, especially as any one item might include dozens of different chemicals. Tracer techniques offer probably the most sensitive methods of detection, since they can cope with concentrations down to 0.01 parts/m. and are quick and economical. The firm of Tracerlab, of U.S.A. held some year ago a colloquium on "The applications of radioactivity in the food and food processing industries." Firms such as this could be of great use in the sound implementation of the new legislation.

Last month in my comments about the activities of Humphreys and Glasgow I said they were teaming up with the American Babcock and Wilcox to supply nuclear power plants in the 17.5 MW to 30 MW range. They have, of course, made the agreement with the British Babcock and Wilcox and it is in no way connected with the American firm. I apologize for the error and for my subsequent comments.—*Nuclearist.*

# NUCLEAR NEWS


- **U.S. N-Industry Looks Ahead** *(This page)*
- **U.K.A.E.A. Make Artificial Element** *(Page 83)*
- **N-Briefs** *(Page 84)*


## The Next Decade

THE atomic industry in America finished 1959 looking ahead to the next decade encouraged by evidence of an increasing willingness of reactor manufacturers to offer qualified guarantees of nuclear power costs, by a ten year U.S. Atomic Energy Commission plan for attainment of economic nuclear power and by continual progress in the construction and operation of actual nuclear projects and programmes, according to an end-of-year review issued by the Atomic Industrial Forum, the association of the American nuclear industry. Dampening factors for certain segments of the industry says the Forum were a slow-down in the EURATOM nuclear construction programme, the trimming down of certain U.S. government reactor development programmes, overproduction of uranium, and a more conservative appraisal of the current value to industry from utilization of radiation and radioisotopes.

## EURATOM-Deutsche

A DISCUSSION has taken place between the president of the Commission of the European Atomic Energy Community, Etienne Hirsch, EURATOM Commission members Krekeler and Sassen, and members of the German Federal Cabinet. The talks were concerned both with the current co-operation between the Federal Government and the Commission as well as with the future development of the Community. Special attention was devoted to the question of implementing the agreement for co-operation on the peaceful uses of atomic energy concluded between the European Atomic Energy Community and the Government of the United States. During the discussions, the Federal Government reiterated its intention of giving every support and encouragement to the German project of the Arbeitsgemeinschaft Kernkraftwerke Stuttgart to build a 150 MW reactor during the first phase of the joint EURATOM-U.S.A. programme. This intention is most concretely expressed by the promise to grant the scheduled federal guarantee of approximately DM.100m.

## Manipulator Order

THE GEC Ltd., of England is to supply a power-operated manipulator for the new nuclear research laboratories being constructed for the Central Electricity Generating Board at Berkeley, Gloucestershire. Value of the order is about £12,000. As previously announced, these laboratories will be equipped for the examination of irradiated fuel elements and of samples of structural components removed on a programmed basis from the Board's nuclear reactors, for monitoring purposes. The GEC power manipulator will form part of the handling equipment for these materials, many of which will be intensely radioactive.

## Plutonium Fuel Tests

FLOW tests on the first fuel element fabricated for use in the plutonium recycle test reactor (PRTR) at the GEC's Hanford (U.S.A.) atomic energy plant have been started. The project is a long range experimental programme expected to lead to the use of plutonium as a fuel for nuclear reactors. Primary function of the flow tests is to determine the effect of the fuel element shape on the overall characteristics of the flow of the reactor cooling water. These tests will also provide valuable information on the ability of the fuel element to stand up under reactor operating conditions. Flow testing of the initial PRTR element is being conducted in a prototype mock-up of a single PRTR process tube. The mock-up duplicates in every possible way operating conditions that will be encountered in the reactor, now under construction. Many of the fittings are the same that will be used in the completed PRTR. PRTR fuel element number one is 8 ft 4 in. long, and weighs around 150 lb. It is classified as a 19 rod cluster. The 19 rods are actually tubes fabricated of zircalloy-2, an alloy of zirconium which is coming into greater use in reactors because of its corrosion resistance, low capture rate of neutrons and other features. Each zircalloy tube is filled with about 6½ lb of unenriched uranium dioxide powder. After the powder is compacted in the tube by vibration, the tube is closed off and swaged. The tubes are then capped and wrapped spirally with zircalloy wire. When the tubes are bundled together, the wire provides separation between the tubes to permit reactor cooling water to circulate around each one. The bundle is held together by means of zircalloy and fittings.

## Calendars Received

WE acknowledge with thanks calendars received from the following:—Stewarts & Lloyds, Ltd.; H. J. Ryman Ltd.; The Hunting Group of Companies; Arthur C. Smith Ltd.; Cape Asbestos Co., Ltd.; The Anderson-Grice Co., Ltd.; General Electric Co., Ltd.; Danfoss Nordborg Denmark; Kodak Ltd.; British Insulated Callender's Cables Ltd.; The Savoy Agency; Mavor & Coulson Ltd.; Spicers Ltd.; Hawker Siddeley Industries Ltd.; Watford Electric & Manufacturing Co., Ltd.; John Laing & Son Ltd.; Hugh Wood & Co., Ltd.; Midland Electric Manufacturing Co., Ltd.; George Anson & Co., Ltd.; Ashwell & Nesbit Ltd.; Turner Brother-Asbestos Co., Ltd.; Le Bas Tube Co., Ltd.; The Holman Group; Caterpillar Tractor Co., Ltd.; Thos. Storey Ltd.; Edwards High Vacuum Ltd.; Burdette & Co., Ltd.; Crofts Ltd.; J. C. Bramford Ltd.; Shaw, Son & Greenhalgh Ltd.; The Watkin Heating Co., Ltd.; Grierson Ltd.; Edward Deane & Beal Ltd.; Heating & General Engineering Co., Ltd.; W. T. Henley's Telegraph Works Co., Ltd.; Matthews & Yates Ltd.; Supervents Ltd.; Cable Supports Ltd.; George Wimpey & Co., Ltd.; Hall Harding Ltd.

## *Dam for N-Station Water*

**The £600,000 dam at Clatworthy, Somerset, designed to hold back 1,100m. gal of water for supplying water for the Hinkley Point nuclear power station as well as water for more normal needs in the neighbouring districts of Taunton, Willington and Wellington. Overall length of the dam is 817 ft and its maximum height 104 ft. Main contractors for the project were Holland & Hannen and Cubitts (Gt. Britain), Ltd.**

## Reactors on the Way

CONSTRUCTION of three versatile facilities to strengthen nuclear reactor research programmes has started at the Argonne National Laboratory, Lemont, Illinois. Two of the units are critical assemblies—Zero Power Reactor 6 (ZPR-VI) and Zero Power Reactor 9 (ZPR-IX)—that will be used to obtain information needed in the development of fast reactor concepts. They are due to be completed in mid-1961. The other facility—" Juggernaut "—is a low-flux, special purpose research reactor scheduled to be completed late in 1960. ZPR-VI and ZPR-IX will be used to check experimentally the accuracy of theoretical calculations on fundamental reactor design. " Mock-ups " of various fast reactor cores will be made and their characteristics and behaviour will be measured. "Juggernaut" is a light water reactor fuelled with highly enriched uranium (U-235). It will operate at a maximum power level of 250 kW. It is octagonal in shape, 10 ft high and 21 ft in diameter. Many of the reactor's faces will be perforated by a number of openings, permitting access to the neutrons for experimental uses. Two of the openings will be lined with graphite to provide slow neutrons. One face is made up of rectangular concrete blocks which are removable, allowing access to the reactor for large-scale experiments such as those involving bulk shielding.

## Artificial Element Made

THE United Kingdom Atomic Energy Authority has perfected a process to extract —from waste fission production solutions—a radioactive element called technetium which cannot be obtained from natural sources. Technetium is one of the radioactive elements which result from the fission of the uranium atoms in the fuel elements of nuclear reactors and is freed from the spent fuel elements when they are processed for the recovery of plutonium and uranium. The element has not yet been found in nature and will probably remain undetectable because only infinitesimal quantities are produced in uranium ores. Until recently, gram quantities were available from the United States Atomic Energy Commission. But now, chemists at the United Kingdom Atomic Energy Authority's Windscale works have produced some 20gm of technetium in the pure state. For this, over 100 tons of waste fission products had to be processed. An ion exchange resin was used for the initial separation of the element which was then removed from the resin with strong nitric acid and concentrated by evaporation. Further purification and concentration was afforded by extraction into the solvent methyl-ethyl ketone which was finally removed by evaporation. A considerable amount of work remains to be done on this element to determine its chemical and physical properties and a number of university laboratories are engaged on technetium research programmes. It was first produced in 1937 at the University of California by bombarding molybdenum with neutrons.

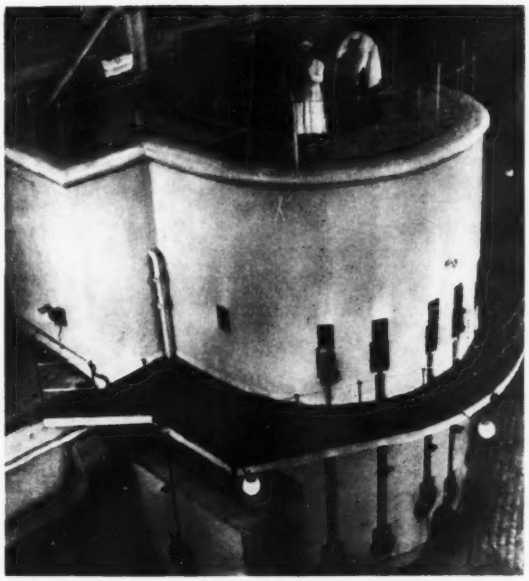
## Argonne's Fast Reactor-AFSR

**The Argonne Fast Source Reactor operated by Argonne National Laboratory at the U.S. National Reactor Testing Station, Idaho Falls. It is being used to augment studies of fast reactor physics currently being carried out in Argonne's Zero Critical Facility (ZPR-III). It is fuelled with uranium-235 consisting of 4½ in. discs canned in metal**

## Superheat Proposal

A $2.7m. study proposal by the GEC of America for increasing the efficiency of nuclear power plants by superheating steam has been selected by the U.S. Atomic Energy Commission for contract negotiations. The nuclear superheat programme will be carried out by the General Electric Atomic Power Equipment Department (APED) at its San Jose facilities and its Vallecitos Atomic Laboratory at nearby Pleasanton, California. The proposal was one of two selected from among nine submitted by various companies to the USAEC. The object of the study is to investigate methods to add more heat to the steam produced by water-type nuclear reactors. Currently these reactors produce steam in a saturated form. An increase of nuclear fuel in the core of the nuclear plants simply generates more saturated steam.

## Soviet Reactor Goes Critical



**Research reactor which recently went into operation at the Institute of Physics of the Georgian SSR Academy of Sciences**

## Fuel for N-Ship

FABRICATION of the fuel elements for *N.S. Savannah's* second reactor core is under way. Half of the uranium needed for this—14,175 lb of 3.9 per cent. enriched uranium oxide in powder form—is being supplied by the Mallinckrodt Nuclear Corporation, of St. Louis, Missouri. The GEC are making the powder up into elements at their St. Jose, California, facilities. Mallinckrodt supplied 20,000 lb of 4 per cent. enriched uranium oxide for *Savannah's* first core. *Savannah* is scheduled for initial operation during the coming summer. One fuel loading is estimated to last for more than 300,000 miles. Before that distance has been travelled however, the first fuel loading will have been removed for testing and examination and the second core installed.

# N-Briefs

John Brown & Co., Ltd., have formed a new wholly-owned subsidiary company, John Brown (SEND) Ltd., to deal with the parent company's activities in the special engineering and nuclear fields.

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A symposium on radioactive isotopes in clinical medicine and research was recently held in Bad Gastein, Austria. Arranged by the Second Medical University Clinic, Vienna, the symposium was attended by experts from all over the world.

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Scientists and engineers working on the OEEC DRAGON project recently held a four-day technical symposium at Bournemouth on the use of graphite in reactor fuel elements. Some 90 delegates, from government organizations and private firms in 10 European countries attended.

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The American Welding Society have published a 20-page report on welding ferrous materials for nuclear power piping operations. Compiled by nuclear power experts, it represents their combined knowledge of the best methods and procedures to be used in this new industry.

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The United Kingdom and EURATOM have agreed that it is desirable to organize and develop close collaboration in the study of controlled thermonuclear reactions for peaceful purposes including exchange of personnel and comparison of programmes with the object of avoiding unnecessary duplication of effort.

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The fifth nuclear reactor built and installed by Atomics International for research centres abroad under the United States "Atoms-for-Peace" programme is now operating in Milan, Italy. It is a 50,000w research reactor located at the Enrico Fermi Nuclear Study Centre of the Milan Polytechnic Institute. Enriched uranium in solution is used as fuel.

* * *

ZENITH, the high temperature zero energy reactor at the Winfrith Atomic Energy Establishment, has started operation. The final stages of commissioning of the plant are now being carried out. ZENITH, which is the first reactor to be built at Winfrith (it was described in NUCLEAR ENERGY ENGINEER, September, 1959), will initially be used by scientists working on the OEEC DRAGON project.

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The research and development department of the United Steel Companies Ltd., in conjunction with Samuel Fox and Co., Ltd., a United Steels subsidiary have developed a new range of high strength stainless steels for elevated temperature service. Called Jethete steels, they are 12 per cent. chromium-nickel steels, containing additions of molybdenum, vanadium, niobium and other elements.

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Burghart, Hurle and Associates, Consulting Engineers, of Wool House, 578, Bourke Street, Melbourne, Victoria, Australia, have opened additional offices at 208, Clarence Street, Sydney, New South Wales. Principals of the firm are Mr. R. Burghart, MIMechE, AMIEAust, MConsE, and Mr. R. H. Hurle, MIEAust. AssocIEE.

* * *

An order for five sets of combined changeover and safety valves for the Advanced Gas Cooled Reactor at Windscale has been received by Cockburns Ltd., of Cardonald, Glasgow. The valves will be used in the $CO_2$ circuit. Cockburns have supplied valves and fittings for the nuclear power stations being built at Bradwell, Hinkley Point and Hunterston.

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Borated graphite blocks used in the shielding to the fast breeder reactor at Dounreay, Caithness, which went critical recently, were made and machined by the Morgan Crucible Co., Ltd., at their Norton works, near Worcester. The purpose of the borated graphite is to slow down fast neutrons and then absorb them in the shortest possible distance, thus providing a safety screen.

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Twelve hundredweight of sheets of special nuclear emulsion made by Ilford Ltd., the photographic manufacturers, have been supplied to American scientists carrying out atmospheric investigations. The emulsion, to be flown in two specially constructed gondolas at a height of more than 100,000 ft, will record the disintegrations produced by nuclear particles coming from outer space.

The second of the two self-propelled mobile radioisotope laboratories donated to the International Atomic Energy Agency by the United States of America has been handed over. It will be used initially at several training establishments and universities in Mexico during the first part of 1960 and then sent to tour the Argentine. The first laboratory has already been extensively used in Europe and is now probably going to be sent to the Far East.

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Associated Electrical Industries Ltd., have established a number of selling companies overseas trading in the name of AEI. The first of these to become operative was AEI (Canada) Ltd. Further companies are Associated Electrical Industries Central Africa (Private) Ltd., Associated Electrical Industries South Africa (Proprietary) Ltd., Associated Electrical Industries (N.Z.) Ltd., and Associadas Electro-Industriais do Brasil Lda.

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Construction of Canada's first nuclear-electric generating station has reached the half-way mark. The $32m. Nuclear Power Demonstration (NPD) project, being built by Atomic Energy of Canada Ltd., Canadian GEC Ltd., and Ontario Hydro, entered a new stage recently when contractors began installation of mechanical and electrical equipment in the powerhouse. First components of the station's 20 MW conventional turbo-generator arrived at the site late in November.

## American Firm's "Hot Cell"

**Described as the world's largest privately-owned facility for the remote examination of radioactive materials is a hot cell located in Atomics International's nuclear field laboratory in the Santa Susana Mountains near Los Angeles. It is designed for the examination of fuel elements from the Sodium Reactor Experiment (SRE) and the Organic Moderated Reactor Experiment (OMRE) and also for examination of the irradiated test fuel elements for the sodium graphite reactor power plant Atomics International are building at Hallam, Nebraska. The cell, covering an area of 17,799 sq.ft, consists of four large shielded compartments with related operating and service galleries, decontamination areas and equipment and storage space. The compartments are large enough to allow disassembly and examination of large reactor components including control assemblies and whole cores**

# Physical Society Exhibition

## Scientific Instruments and Apparatus on show at the Horticultural Halls, London

ONCE again the Physical Society's annual exhibition of scientific instruments and apparatus demonstrates vividly the versatility and skill of British achievements in this field, and once again it is proving a popular event. There are 140 exhibitors at this, the 44th, show in the series, and many of their exhibits are on show for the first time. As in previous years and as, we are warned, will happen again, several firms who had hoped to exhibit have had to stand down due to lack of space—the two Horticultural Halls of Vincent Square, Westminster, are jammed tight. It makes one wonder whether it would not be appropriate for the Society to find larger exhibition premises.

As before, the exhibitors include not only industrial firms but also national and governmental research organizations and the research departments of hospitals and universities. As a special feature of this year's exhibition there is a display of Swiss instruments and equipment, arranged with the co-operation of the Swiss Physical Society and the Swiss Office for the Development of Trade. Another special feature is the Physical Society's colour group demonstration, which aroused considerable interest when staged last year.

### IN THE NEW HALL

The Swiss display the visitor to the exhibition will be able to see as he enters the New Horticultural Hall—it is to the left of the vestibule. Six Swiss firms are represented—**Landis & Gyr AG,** who show equipment for the control of radioactive contamination of liquids; **Metrohm AG,** the Metrohm potentiograph E.336, an apparatus for the automatic recording of titration curves; **Emile Haefely & Co., Ltd.,** who in conjunction with the Physical Institute of Basle exhibit a 1:10 model of a 4 MV ion accelerator; **Trüb, Täuber & Co., Ltd.,** an electron diffractograph designed to solve any diffraction problem; **Ebauches SA,** a fully transistorized 100 Va amplifier and a high stability time signal generator; and the **Oerlikon Engineering Co.,** who are displaying sections of bending and quadrupole magnets as well as some photographs of small laboratory magnets.

Also in the vestibule are the various university displays and also that of the **Medical Research Council.** The latter includes a scintillation counter for gas liquid chromatography developed by the **Experimental Radiopathology Research Unit, Hammersmith Hospital.** It is designed to measure the radioactivity of organic vapours emerging from a gas-liquid chromatographic instrument in parallel with the normal analytical chromatographic recording. The vapours are conducted along a heated tube into circulating liquid phosphor and the scintillations excited in it are measured with a photomultiplier tube. The instrument is used in conjunction with a gas density meter.

### *More Radiation Equipment*

Another apparatus for measuring radioactivity on the MRC stand is a portable high-pressure ionization chamber designed to measure background radiation developed by Professor F. W. Spiers, of the **Medical Physics Department, Leeds University.** It consists of a 0.12 in. thick chamber containing nitrogen at 50 atm. The change of potential of the central electrode is measured by applying a balancing voltage to the grid of a miniature triode in a Townsend balancing circuit. A rate of drift observation of 3 min to 4 min duration will determine the gamma-ray dose rate of the order of 10 micro-rad/hr, with a standard error of $\pm$ 1.5 per cent.

Radiation is also the subject of one of the **Reading University** exhibits. This consists of a cell for the electron irradiation of a specimen and subsequent measurement of its electrical conductivity at low temperatures, and a furnace for annealing studies on irradiated specimens.

From the vestibule the visitor has the choice of nine avenues down which to start his tour of the main exhibits. For some unknown reason the avenue on the extreme left, unlike the others, is un-named (the others are named after famous physicists, as also are two of the avenues in the Old Horticultural Hall. But that surely sti'l leaves several more names that could also be used?). Two of the stands of special interest down this avenue are those occupied by the member firms of the **Associated Electrical Industries Group** and by **Edwards High Vacuum Ltd.**

### *For Fusion Research*

On the AEI stand **Sunvic Controls** are showing a prototype of a new unitized pulse counting system for reactor flux measurement and control, radiation monitoring and fission production detection. Another exhibit here, by the electronic apparatus division of AEI, is of ignitron switches for thermonuclear research. They are designed to withstand voltages of up to 25 kV (forward and inverse) and to pass currents of peak value 40,000 amps and 80,000 amps.

A special feature of the stand is the exhibits staged by the AEI Research Laboratory at Aldermaston. Among these are a thermoelectric recording hygrometer, and an electron optical bench for studying the focusing properties of magnetic quadrupoles. **The Metropolitan-Vickers Electrical Co., Ltd.,** now officially named AEI (Manchester) Ltd., show a Newton Victor 60 X-ray fluorescence spectrometer, X-ray microanalyser, and various diffusion pumps, among other things.

Pumps are of course the subject of the nearby Edwards stand, which this year is devoted to ultra-high vacuum. Several pumping systems and auxiliary equipment are shown, including one of the 40 pumping

groups being supplied for the 7 GeV proton synchrotron NIMROD being built at the Rutherford High Energy Laboratory, Harwell. With some of the apparatus shown pressures lower than $5 \times 10^{-11}$ torr can be obtained.

### Two Expendable Pumps

Opposite, **Mullard Ltd.** are also showing a range of high vacuum equipment including expendable getter-ion pumps. Two models are shown. The first is a Bayard-Alpert ion gauge with a filament from which titanium may be evaporated while the gauge is pumping. The second consists of a single loop of wire from which titanium may be evaporated, and a side contact through the glass envelope. Mullards are also showing microwave devices, semiconductors, cathode-ray tubes radiation detector tubes, reflex klystrons, and computer equipment.

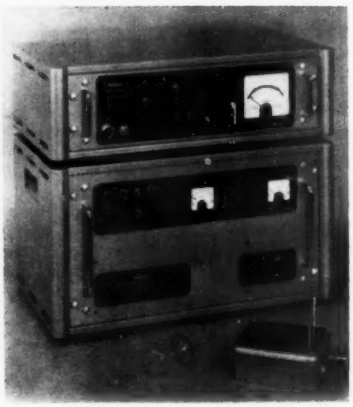
Similar equipment will be found on the neighbouring stand, occupied by **Elliot Brothers (London) Ltd.** In addition a prototype magnetic wire matrix storage system is demonstrated.

Before going along to Elliot's the visitor might care to have a look at the range of equipment displayed by **Dawe Instruments Ltd.** (No. 118), the specialists in acoustic equipment. Much of it is new including, type 720 transistor oscilloscope, a completely self-contained instrument operating from an internal accumulator and because of its lightness it is particularly suitable for operation in transport.

### Smart Appearance

Soon the visitor will find himself in Davy Avenue and while wandering down it his attention is sure to be caught by the smart looking equipment displayed by **Rank Cintel Ltd.** On show are their delayed pulse and sweep generator, a new fully transistorized scaler, a universal counter timer with print-out unit, automatic radiosonde telemetering equipment, printed circuit counter panels and a new demonstration oscilloscope. Still under development by Cintel are a 10 Mc/s printed circuit decade unit, and, based on this unit, a decimicrosecond chronometer, an improvement on the current microsecond chronometer, and a 10 Mc/s universal counter timer.

Directly opposite Rank Cintel **Baldwin Industrial Controls** are showing a range of nucleonic thickness gauges, including a prototype transportable beta gauge which is a simplified version of their "Atomat".



**Ion current amplifier and emission control unit mounted in standard 19 in. rack cabinets. Shown by Edwards High Vacuum Ltd.**

### Prototype Equipment

Behind, facing on to Kelvin Avenue, **Cossors Instruments Ltd.,** have a stand on which they display a range of electronic equipment including a prototype high speed single-beam oscillograph. This has a 5 in. tube with an overall accelerating potential of 10 kV and interchangeable plug-in units provide for a very wide performance selection for both the vertical and horizontal channels. Also new are a high writing speed cathode ray tube with triggered time-base and time and voltage measurement, a modified version of a standard millimicrosecond pulse generator, and a 3 in. tube transistorized oscillograph.

**Sir Howard Grubb, Parsons & Co., Ltd.,** in Thomson Avenue display spectrometers, an infra-red gas analyser and an advanced version of a fixed wavelength analyser using a diffraction grating. At the other end of the avenue the **Solartron Electronic Group** display a range of their electronic equipment. New is the fast digital printer. It is of unit construction, each unit having 15 digits and ten units can be connected in line to give a total of 150 digits a line. The print pitch is 6 digit/in. and normal printing is 6 line/in., although 3 line/in. can be selected. The printing speed is 10 line/sec and two-colour printing is possible.

One of the largest stands in the exhibition is that of the **United Kingdom Atomic Energy Authority,** appropriately sited in Rutherford Avenue. Arranged by the Patents Exploitation Branch of the Authority. the exhibits are of the most recent inventions of the various Authority research establishments and divisions. One of the exhibits is a hydraulically operated trolley capable of operating with very heavy loads in confined areas. Another device is an electrically operated combination door lock. With 12 buttons of which four are depressed two by two in any order, the lock offers 43,356 possible four-letter or four-figure codes. Any one of these can be set up in a few seconds while the interlocking electrical warning circuits prevent the correct sequence from being discovered by trial and error methods.

Among the instruments shown by the Atomic Weapons Research Establishment, Aldermaston, is the "gravity photo-sedimentometer for particle size determination." It is designed to determine particle size and particle size distribution in powdered materials within the range of 5 to 70 microns. It has application in many industrial fields.

### Mercury Vapour Detector

Another interesting AWRE item is a portable detector for mercury vapour. It is based on the fact that dominant radiation from a low-pressure mercury vapour lamp—2537 Angstrom—is absorbed by mercury vapour in the air through which it passes.

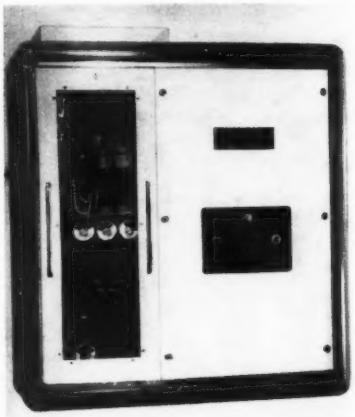
A detector of a different kind is shown by the Chemistry Division's Outstation at Woolwich. This is for the direct determination of beryllium and its intermediates in the atmosphere. The air is drawn through a triggered a.c. arc and the emitted light, after dispersion through a grating monochromator is measured by two photomultipliers (line and background) and presented to a ratio recorder. The instrument is programmed to carry out one determination/min on an automatic repetitive cycle and provision is made for calibration at pre-set intervals.

Also from the Chemistry Division is a demonstration of the automatic recording of wavelength measurements by use of moire fringes and photoelectric scanning. The use of the moire fringe principle for measuring the precision measurements of small displacements is finding increasing use in industry and at this

exhibition there are at least six displays showing application of what is an old principle.

Harwell's Accelerator Division has devised a number of working and non-working models illustrating how heat can be directly converted into electrical energy. Also from Harwell is the Isotope Division's radioisotope X-ray spectrometer for the rapid analysis of alloys, using a low-powered radioactive source whose radiation excites fluorescent X-rays in the sample. These are analysed with a proportional or scintillation counter.

Scintillation counters are shown on an adjacent stand by **Panax**



**Polarographic pre-treatment unit, de-designed for use in conjunction with an external polarograph for automatic process monitoring. Shown by Baird and Tatlock (London) Ltd.**

**Equipment Ltd.**, who are also showing for the first time a new automatic counting equipment for use with Geiger or scintillation counters.

Also near these stands in Rayleigh Avenue is a display of some new spectrophotometry equipment by **Optica United Kingdom Ltd.** There is the new double beam ratio recording reflectance spectrophotometer CF4 which is an adaptation of the recording spectrophotometer for solutions. It incorporates an Ulbrich sphere and measurements against magnesium oxide are recorded directly.

### For Corrosive Fluids

At the other end of Rayleigh Avenue can be seen an ultrasonic flowmeter for measuring the flow of "difficult" fluids, such as corrosives or fluids which contain suspended material which might impair the performance of more conventional type meters. As it is non-constrictive there is no head loss associated with the ultrasonic flowmeter. It is designed to measure relatively slow flow rates and it can be fitted to pipes of diameters between 1½ in. and 12 in. It has been developed by the **British Scientific Instrument Research Association.**

### "New" Metals shown

Examples of tubing in the "new" metals are displayed by **Accles & Pollock Ltd.**, the metals being tantalum, niobium, zirconium, molybdenum, vanadium, and titanium. **Murex Ltd.**, are also showing items fabricated from these metals.

One exhibit in the New Hall the visitor should not miss is the model of the periscope designed to enable operators at the Berkeley nuclear power station to see within the reactor pressure vessels. Such a periscope would be normally used during "closed down" conditions of the reactor but could also be used under full load conditions during an emergency. Without moving his position and in complete safety the operator will be able to view the contents of the pressure vessel and by turning the handwheels traverse and elevate or depress his line of sight. The makers of the periscope are **Barr & Stroud Ltd.**

**Research cathetometer displayed by R. & J. Beck Ltd.**

## IN THE OLD HALL

Entering the Old Hall from Vincent Square to view the rest of the exhibition, the visitor's attention will most likely be divided between the stands opposite the entrance occupied by **The Plessey Co., Ltd.**, on the left and **Ferranti Ltd.**, on the right. Plessey are showing a wide selection of their latest developments in electrical, electronic, electro-magnetic and nucleonic engineering. In the nucleonic field are displayed a number of radiation detectors including one specially designed for detecting plutonium in the body. Others are for particular use for monitoring milk and water supplies.

### Computer Focal Point

Focal point of the Ferranti stand is a demonstration of the Sirius computer, a small fully transistorized computer which can be plugged into any standard 230v 5 amp socket. The firm is also showing semi-conductor devices, ceramic-metal assemblies and cathode-ray tubes.

Adjoining the Plessey stand is a display of nucleonic equipment by **Burndept Ltd.** Included are a portable thickness gauge which uses beta backscatter techniques for measuring plate thickness, an industrial radiation switch which in conjunction with a beta or gamma active source may be used for level control, the monitoring of cartons and package counting, among many applications, a radiation monitor ratemeter and a scintillation counter.

More electronic equipment will be found on the **Ekco Electronics Ltd.**, stand. Amongst the range of ratemeters, counters, monitors, and amplifiers, displayed is the prototype automatic scaler. This has an overall resolution of 1 microsecond and an automatic pre-set time and count.

**Isotope Developments Scaler 1800**

The visitor particularly interested in this type of nucleonic apparatus should not miss the prototype precision ratemeter on the nearby

**Isotope Developments Ltd.,** stand. This is a highly accurate and stable multi-range ratemeter giving both linear and logarithmic display. It incorporates high voltage supply, amplifier and pulse height selector and can therefore be used directly with a G-M tube or scintillation counter. Other equipment on this stand includes a beta thickness gauge for paper, plastics, light metal foils, etc., and a gamma alarm.

### *The DSIR Exhibits*

Other firms exhibiting nucleonic equipment in this part of the hall include **Lagbear Ltd., Cawkell Research and Electronics Ltd., Claude Lyons Ltd., E.M.I. Electronics Ltd., Hatfield Instruments Ltd., Lintronic Ltd., and Texas Instruments Ltd.**

At the far end of the Old Hall the **Department of Scientific and Industrial Research** have arranged a display of equipment and apparatus used by several national research associations. One of the most fascinating of the exhibits here is of the demonstration of measuring the "substance" or weight per unit area of felt hats with a nucleonic thickness gauge. In the manufacture of felt hats the control of the substance is very important because the hat bodies, which are roughly conical in shape, are stretched and moulded into various shapes after having been heated and wetted in steam. If the geometry and build of the bodies are not suited to the hat shapes which have to be produced the hats show local areas where the felt is thin and broken. These might cause distortions in the hat when it is subsequently wetted by rain. Using a nucleonic gauge enables non-destructive testing to be carried out; previously samples of the felt had to be cut out of the hat bodies and separately weighed, and complicated drawings and calculations carried out to assess the pattern of local stretches in the hat. The apparatus is demonstrated by the **British Hat and Allied Feltmakers Research Association.**

### *Shown at World Fair*

Another interesting exhibit in the Old Hall is the **Science Museum's** working model to illustrate the principle of the cyclotron. A similar model was shown at the 1946 Exhibition; this is an enlarged and much improved version made at the Hammersmith Hospital for the Medical Research Council and shown at the Brussels World Fair in 1958.

## Fluidized Bed Equipment

THREE research workers of the United Kingdom Atomic Energy Authority have devised apparatus which is claimed to give more trouble-free and accurate indication of conditions prevailing in fluidized bed processing equipment than earlier probe devices based on electrostatic or pneumatic systems. The new apparatus measures electrically the heat transfer coefficient within the fluidized bed in the region of a heated probe and thus gives an indication of the conditions prevailing around it. Fluidized bed operations, specially suited as they are to continuous processing, are steadily gaining ground in many sectors of the chemical industry. The fluidized bed is a most effective means of obtaining intimate contact between granulated material and a stream of gas or vapour, to produce a chemical reaction, or to promote drying or humidifying. So far, instruments intended to record changing conditions of fluidization have often been limited in their use to materials with low electrical conductivity and have tended to clog with the materials being processed. Furthermore, in many cases, the probe used is of necessity so large that it causes perturbations in its vicinity, though uniformity exists throughout the rest of the bed. Other types of apparatus are too prone to mechanical shock damage. The new apparatus, devised to avoid these pitfalls, consists of an electrically-heated probe maintained at a higher temperature than the bed and means to measure the power fed to the probe to maintain it at constant temperature. Any perturbation in the fluid surrounding the probe will be reflected by a fluctuation in the power fed to it.

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**TABULAR DEVICE**

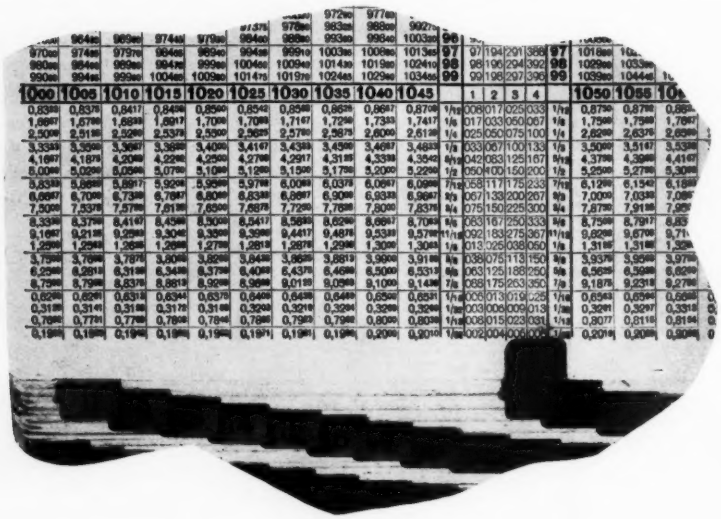
(*Continued from page 78*)

10.50 (or 10*s.* 6*d.*) per hour =
0.175 (approximately 2¼*d.*) per minute

$^1/_3$ of 10.50 (or 10*s.* 6*d.*) =
3.5 (3*s.* 6*d.*)

Yearly total: 105
less 1 month: 96.25 (read at $^{11}/_{12}$)

1045 and 1050 combined:



What is 31 per cent. of 1045105
= 323950
32.55
323982.55

*Example of a division:*

Table 10.

280 The divisor is 10, we go into
10 table 10, column 10.00 and go down in that column until we find 280. In the vertical column we find 28.

219.45 Divisor 10.45—go down
10.45 the column as far as 219.45. Next to it, in the vertical column, is the result: 21.

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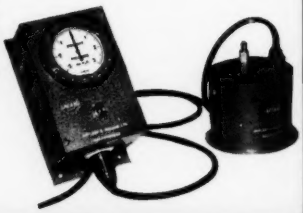

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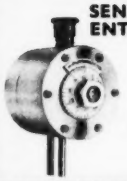

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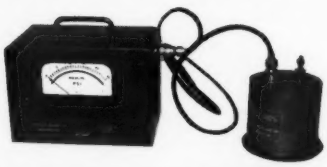

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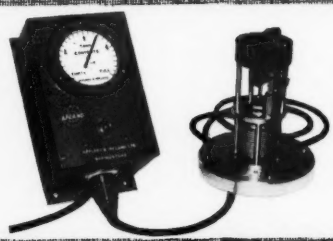

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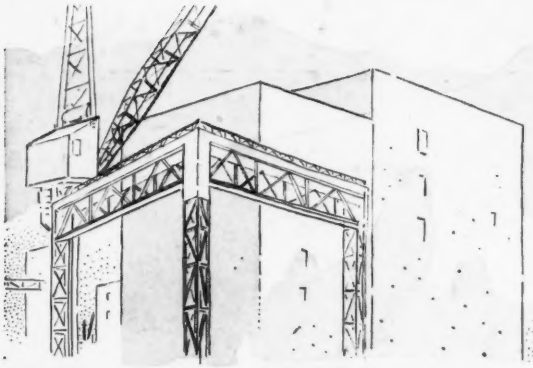

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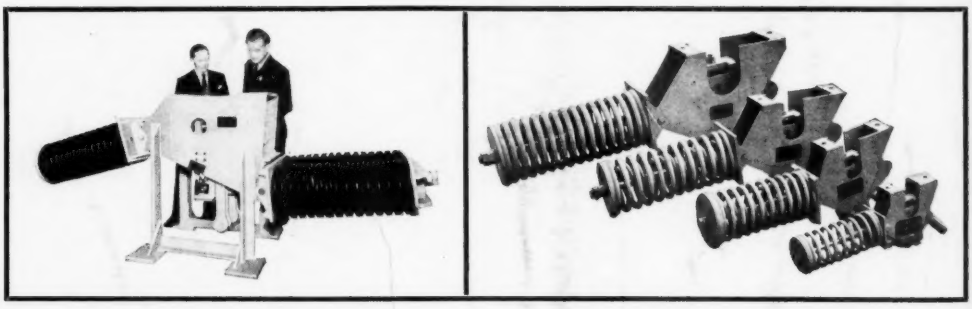

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